FIELD-EDGE PLANTING TO DETER WHITE-TAILED DEER AND ATTRACT CARABID BEETLES IN SOYBEAN FIELDS

by

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Submitted in partial fulfilment of the requirements
for the degree of Master of Science

at

Dalhousie University
Halifax, Nova Scotia
August 2014

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ABSTRACT

In many cropping systems, farmers have to contend with invertebrate and vertebrate pests, but there have been few attempts to employ Integrated Pest Management (IPM) strategies and tactics that simultaneously manage these problems. This study tested whether or not damage to soybean from white-tailed deer could be reduced by field-edge plantings, while increasing the abundance of predatory ground beetles in the same soybean fields and subsequently reducing numbers of soybean aphid, *Aphis glycines*, on soybean plants. The 2012 field season had five perimeter treatments. There were no significant effects of treatment on factors of interest, but there were significantly more deer presence, deer grazing damage, and carabidae captures at areas close to field-edge as opposed to 20 m into crop field. In 2013, plot sizes were increased and treatments were decreased. The two treatments in 2013 were: alfalfa + red clover + orchard grass and soybean (control). Deer grazing damage to soybeans was significantly lower in areas adjacent to a legume + orchard grass field edge planting. Significantly more carabids were captured in field areas associated with legume + grass perimeter plantings. Soybean aphid population densities were low throughout the study and their numbers were not significantly affected by perimeter treatments. In conclusion, the results of this research suggest that field-edge plantings may be a potential technique to mitigate white-tailed deer grazing on soybean, while boosting numbers of carabid beetles in the same field.

LIST OF ABBREVIATIONS USED

α	alpha
ANOVA	analysis of variance
cm	centimeter
df	degrees of freedom
etc	et cetera
m	meter
n	number (sample)
ha	hectare
kg	kilogram
mm	millimeter
NS	Nova Scotia
SAS	Statistical Analysis System
X^2	Chi-square

ACKNOWLEDGEMENTS

I would like to acknowledge my supervisory committee, technical staff and student researchers for their help and guidance throughout the course of this project. A special thank-you to N. McLean and C. Cutler for helping me develop the concept of the project and pointing me in the right direction. I would also like to acknowledge the Growing Forward Initiative for funding this project. Thanks to all of the producers who so generously donated their land and helped with seeding. Finally, I would like to thank my family, friends, and colleagues for their help, encouragement and support. I am sincerely grateful to have so many wonderfully supportive people in my life.

CHAPTER 1 INTRODUCTION

Damage and loss of crops caused by arthropod and non-arthropod pests is an important problem. Although there are several management options, including chemical, cultural, mechanical, and biological control, the most common control methods used by producers typically involve the use of one or more chemical pesticides. Pesticides can have adverse effects on the health of humans and non-target organisms (Smith and Calvert 1976). The use of chemicals like organophosphorus pesticides for insect pest management has resulted in declines in populations of biological control (biocontrol) agents and other beneficial insects, and emergence of insects resistant to pesticides (Ignacimuthu 2007). Pesticides can have adverse effects on the health of humans and non-target organisms (Smith and Calvert 1976).

In light of growing concerns regarding pesticide use, biointensive integrated pest management (IPM) or "ecology-based pest management" is being encouraged more widely in agroecosystems. The IPM approach was developed as a solution to the need for comprehensive, ecologically oriented multi-pest management systems. IPM implements a whole system approach in order to reduce pest damage to tolerable levels using a variety of techniques such as natural predators, parasites, environmental manipulation, and in some cases, chemical control when deemed necessary (Bottrell and Smith 1982). This type of pest management can minimize environmental impact and contributes to the stability of agricultural ecosystems. Although the term "IPM" was not widely used before the 21st century, its tactics were used to defend crops against pests long before the term was coined. Crop protection specialists in the 19th and 20th centuries relied on their knowledge of cultural practices and pest biology to develop multi-faceted pest control strategies, some of which were precursors to modern IPM systems (Kogan, 1998).

IPM is typically associated with insect pest management, but its principles may be applied to vertebrate pest management. The environmental manipulation component of IPM is of interest in this thesis research project as a “push-pull” tactic to potentially minimize vertebrate pest problems in a crop field. Environmental manipulation is a cultural control method that can be implemented in the form of buffer zones or perimeter plantings around agricultural crop fields. Lyon and Scanlon (1987) pointed out the potential of a low-growing buffer zone between a forest edge and the crop field to help minimize browsing damage by white-tailed deer.

1.1 Soybean Production in Canada

Soybean (*Glycine max* Linnaeus) is a species of legume that has been cultivated for centuries as a food for humans, feed for animals, an edible oil crop and, more recently, for industrial purposes such as biodiesel, candle-making and industrial lubricants. Cultivation of soybean in Canada started as early as the mid-1800s (Dorff 2009). Cultivation in Canada was restricted to specific areas of Southern Ontario before the mid-1970’s, because of the short growing season and cooler conditions in the rest of the country (Dorff 2009). With the implementation of intensive breeding programs, the area for cultivation of soybeans has increased about 8-fold, encompassing 1.5 million ha in 2011 (Anonymous 2012a). Ontario is the main producing region for soybeans within Canada, with 987,400 ha seeded in 2011. Quebec and Manitoba are the next highest producing provinces in Canada, having seeded 300,000 and 232,700 ha in 2011, respectively (Anonymous 2012a). PEI seeded 22,300 ha in 2011; no other maritime provinces were included with this data, possibly because the area seeded was minimal (Anonymous 2012a).

Canada is not a major producer of soybean, but a segment of its domestic production is of specialized, high-quality, food-grade beans that are desirable in foreign markets. About 40% of soybeans grown in Canada are for export, sold at an average price of $321 per tonne (in 2006), whereas imported beans averaged $267 per tonne (Anonymous 2012a). Imported beans are of lower quality and are used for animal feed and domestic crushing (Dorff 2009).

1.2 Deer as an Agricultural Pest

White-tailed deer (*Odocoileus virginianus* Zimmerman) is considered an agricultural pest in many food crops, mainly because they consume the cash crop, resulting in a direct loss of yield for the producer (Côté et al. 2004). Browsing rates are generally high early in the season when plants are young and decrease as the plants reach the reproductive stage (Colligan et al. 2011). There is little information regarding exact losses incurred by Canadian farmers (Putman and Moore 1998), though compensation paid to farmers has been reported by the Wildlife Compensation Program (managed by Nova Scotia Crop and Livestock Insurance Commission). In the first two years of the program $57,627 was paid for low-bush blueberry losses, $79,042 for vegetables, and $2,341 for soybeans (Wagner et al. 1997). In 2011, the Nova Scotia Crop and Livestock Insurance Commission reported a payout of $9,940.00 for soybean losses, which includes damage incurred from inclement weather as well as wildlife (Bentley and MacLeod

2011). The amounts claimed do not reflect total damage caused. Many farmers do not purchase insurance, and according to Wagner et al. (1997), compensation programs rarely pay the producers for the full amount of damage incurred. Current management strategies for deer damage to agricultural crops include compensation programs, deterrents (fencing, deterrent sprays), and shooting of deer (Garrison & Lewis 1987; Wagner et al. 1997; VerCauteren et al. 2005; VerCauteren et al. 2006; VerCauteren et al. 2010; Elmeros et al. 2011; Warren 2011). Wildlife compensation programs may not be suitable for all situations. Conflict can arise with regards to damage assessment or exploitation since the producer may have a different opinion than the insurance agent. Compensation programs are not designed to control the problem and though producers may be compensated for losses, future losses may still occur without direct management.

1.2.1 Management of White-Tailed Deer

Various methods have been developed in order to contend with deer, such as odor repellents, fencing, scarecrows, noisemakers, and even human hair or animal blood. Many of these methods are useful on a small scale or short-term basis but there still exists a dilemma for large-scale producers with limited budgets for deer management (Bishop et al. 2007).

Fencing to keep deer out of a particular area is practical in small areas such as residential garden beds, or in high-value crops, but is often impractical for large-scale agricultural operations such as soybeans. Types of fencing typically used to manage white-tailed deer damage include electric fencing, plastic mesh, and wire (chain-link) (VerCauteren et al. 2006). Installing fencing in fields is labour-intensive, timeconsuming, and costly. Moreover, deer are capable of jumping over fences less than 2 m high (VerCauteren et al. 2010).

Odour repellents have been used residentially to help keep animal pests out of garden beds and away from young trees. Most repellents mimic predator scents (e.g. coyote urine), but some use cayenne pepper and others use unpleasant-smelling essential oils. In Denmark, chemical deterrents did not lower visitation rates of deer to baited areas that had been treated with repellent (Elmeros et al. 2011). Deer may have quickly habituated to the scents in this experiment. If the repellent is effective, its cost and associated application may not be practical and could affect other beneficial animals, insects, or organisms. Colligan et al. (2011) reported that chemical deterrents such as Hinder® may work to repel deer but are not cost effective to apply to soybean fields. Noise making devices such as propane cannons and robotic scarecrows may work for a short period of time in small fields, but can be costly (Colligan et al. 2011)

Deer populations can be reduced by eliminating part of the population through increased hunting or culling. In Japan, sika deer populations have fluctuated over many years due to increased and decreased hunting rates (Kaji et al. 2010). Increased hunting of deer has been proposed as a potential management strategy in parts of North America (Warren 2011). Although this may seem like a simple solution, it would be difficult to implement in residential areas and in areas where there is agricultural production (i.e. soybean fields) due to the public safety concerns. According to the Nova Scotia Department of Natural Resources, a special permit may be issued to farmers who demonstrate that they have a nuisance animal(s) but they are required to show that all other options for animal control have been exhausted and that this is the only remaining option. Additionally, the harvest of the nuisance animal must be done in a specified manner and the meat donated to a charitable source (Hall 2013). These regulations may present cost and time barriers thus causing the process of obtaining a special nuisance animal permit unappealing to producers.

Deer have preferences for certain types of forage, and will avoid others. In mixtures of alfalfa, timothy, and orchard grass, deer selectively ate alfalfa and timothy but avoided orchard grass in all cases (Hall and Stout 1999). Lyon & Scanlon (1987) found that 90% of deer were sighted within 50 m of the field-edge, and that more than 50% of deer foraging happened within 20 m of the field-edge. They also noted that the majority of deer (> 90%) were present and foraging in the evenings and suggested that crop management and the use of a planted buffer between the crop field edge and the forest may help to minimize soybean consumption by deer.

1.3 Soybean Aphid (*Aphis glycines)*

Aphis glycines Matsumura (soybean aphid) is usually considered the primary insect pest of soybean (Brown 2011). *A. glycines* is an invasive herbivorous insect, indigenous to Asia and relatively new to North America, first discovered on soybeans in Wisconsin in 2000 (Fox et al. 2005; Ragsdale et al. 2011). Direct damage from stylet-feeding by *A. glycines* can include stunted growth, distorted foliage, curling of twigs, physiological delays in maturity and underdevelopment of root tissue (Tinsley et al. 2012). Indirect damage includes the transmission of diseases and viruses from one plant to another and the excretion of honeydew which promotes growth of sooty moulds that can reduce photosynthetic capacity (Fox et al. 2005; Shi et al. 2011). In Asia, where *A.*

glycines is a major pest problem, an average of 20 cm reduction in height and 27.8% reduction in seed yield has been recorded (Fox et al. 2005).

The lifecycle of *A. glycines* is heteroecious holocyclic, meaning the insects alternate hosts and reproduce sexually during part of their life cycle. *A. glycine* overwinters on primary host as an egg. Primary host plants are buckthorn shrubs of the genus *Rhamnus* and closely related shrubs, which can be found in margins of woodlots and agricultural hedgerows (Bahlai et al. 2010). Eggs are very cold tolerant and can overwinter easily. In spring females migrate to the secondary host plant, soybean, where they reproduce parthenogenetically and rapidly increase their populations. Parthenogenetic reproduction refers to their ability to reproduce asexually without fertilization. The offspring are clones of the female aphid and are born live, as first instar nymphs (Blackman 1979). Controlling aphids is important at this point in the life cycle to ensure that infestations do not develop early in the season (Fox et al. 2005; Bahlai et al. 2010). Aphid colonies have the ability to develop winged individuals who can migrate to other areas in the crop field or to other crop fields (Ragsdale et al. 2004).

1.3.1 Conventional Management of Soybean Aphid

Aphid control typically involves the use of one or more chemical insecticides. Active ingredients from the organophosphorus, carbamate, pyrethroid, and, most recently, neonicotinoid classes, have been used for aphid pest management. Visual assessment is used to determine when chemicals should be sprayed. A threshold of 250 insects per plant has been recommended as an economic threshold (Zhang and Swinton

2012). Alternatively, seed-treatments with systemic chemicals like imidacloprid can protect plants from aphid damage early in the season (Magalhaes et al. 2009).

Many aphid populations have developed resistance to organophosphorous, carbamate, and pyrethroid insecticides, due to widespread use of these chemicals. Neonicotinoids are relatively new and can be used on insects that are exhibiting signs of resistance to the other chemicals, although resistance to neonicotinoids in aphids has developed (Nauen and Denholm 2005; Shi et al. 2011). Aphid-resistant strains of soybean have been bred as an alternative to chemical control of aphids, but productivity of these strains may be unpredictable (McCarville et al. 2012). Biological control is an eco-friendly alternative to chemical control.

1.3.2 Biological Control of Soybean Aphid

Biological control (also known as bio-control) options for *A. glycines* include release of natural predators (originating from the same geographical location as the pest) such as Asian ladybird beetles and/or parasitic wasps when aphid populations are high. This is known as classical biological control (Heimpel et al. 2004). One issue with classical bio-control is the potential negative impact that a non-native natural enemy may have on an ecosystem. Release or introduction of natural enemies into an ecosystem may be counter-productive if the introduced species consumes resident predator species or monopolizes their food source, leading to displacement. An introduced predatory species may also transmit new diseases or reach densities that are too high for the specific environment (Synder at al. 2006). Other types of bio-control include augmentation and conservation. Augmentative bio-control involves supplementing the naturally occurring pest enemies (Collier and Steenwyk 2004). This may be a desirable method for pest control but one barrier that exists is the acquisition of specific naturally occurring enemies that may be difficult to rear in large amounts or in captivity. Conservation biological control may be implemented to encourage resident populations of natural aphid enemies. This biological control method involves ecologically-based techniques to boost or preserve populations of naturally occurring beneficial insects (Thomas et al. 1991; Halaj et al. 2000; Landis et al. 2000; Woltz et al. 2012). Environmental manipulation, which typically involves altering the available habitat for predators, can play a major role in the preservation of natural enemies and affect the impact that the natural enemies have on reducing pest populations (Gullan and Cranston 2006).

1.4 Carabid Beetles as Biological Control Agents

Soybean aphids have several natural predators, including beetles (Coleoptera) from the family Carabidae (ground beetles) (Hajek et al. 2007). Carabidae is the largest family of beetles, comprising over 20,000 species worldwide and about 930 species within Canada. Life cycles and feeding habits of carabid beetles are quite diverse. There are omnivorous, carnivorous, and herbivorous taxa, but adults and larvae of most species are generalist predators that will feed on a wide variety of insects (Goulet and Bousquet 2004). Carabids can play a significant role in reducing herbivorous insect populations in crop fields (Varchola and Dunn 2001; Fox et al. 2005; Hajek et al. 2007). They are generally ground-dwelling insects, but some species of Carabidae such as *P. melinarius* and *A. meurelli* climb soybean stalks in pursuit of aphids (Hajek at al. 2007). Ground beetles can regulate the establishment of aphid in sugar beets (Landis and Van Der Werf

1997), and are important in control of bird cherry-oat aphid in spring barley, and wheat aphids in winter wheat (Lang 2003). As generalist predators, Carabidae are often not as effective *per capita* as more specialized predators, but presence early in the season (when aphid control is most critical) compensates for their lower efficacy (Fox et al. 2005). Their aphid consumption early in the season can help slow down population expansion and facilitate aphid predation by later arriving predators such as ladybird beetles and parasites (Hajek et al. 2007).

1.5 Field-Edge Plantings

Past efforts to protect beneficial insects like carabid beetles have involved timed applications of pesticides to avoid beetle exposure to the pesticide, and the search for selective pesticides that are less toxic to carabids. Recent efforts include examining conservation practices that aim to preserve or enhance the quality of natural enemy habitats (Landis et al. 2000). If there are chemical-free insect habitats surrounding a field that is being chemically treated, the beneficial insects in that habitat may be less affected by insecticides. Agricultural fields generally experience a lot of disturbance from plowing, spraying, fertilizing, etc. and it has been shown that field margins are important habitats that allow for re-colonization of crop fields after a disturbance (Dennis and Fry 1992; Asteraki et al. 1995; Carmona and Landis 1999). Increased beneficial insect and/or beetle populations are associated with alternative refuge habitats within or around fields (Thomas et al. 1991; Asteraki et al. 1995; Halaj et al. 2000; Landis et al. 2000; Menalled et al. 2001; Varchola and Dunn 2001; Fox et al. 2005; Hajek et al. 2007). Hedgerows sown with perennial grasses, including orchard grass, located within crop fields can be used to create refuge habitats for beneficial carabids to sustain their development in an intensive farming operation (Thomas et al 1991). In soybean, buckwheat margins have been used to increase abundance of ladybird beetles that attack soybean aphids (Woltz et al. 2012). Carmona & Landis (1999) planted refuge strips containing perennial flowering plants, orchard grass, white clover, and red clover. Certain carabid species, such as *Harpalus pensylvanicus* Degeer, were more abundant in crop areas adjacent to refuge strips than areas without refuge strips. Grassy margins planted at the edge of soybean fields, adjacent to wooded areas, can act as wildlife corridors to move carabid beetles from wooded areas into the crop field (House and All 1981).

Habitat preferences of carabids include sheltered areas with adequate organic matter. Such habitats can be developed by the construction of beetle banks, which are created by sowing perennial grasses in an area that will experience minimal disturbance (Landis et al. 2000). Ostman at al. (2001) found that landscape structure and farming practice influenced carabid populations in agricultural environments. Predatory species of carabids were more abundant in organic fields than conventional fields. This was attributed to the higher crop diversity in organically managed fields, as opposed to conventionally grown Round-Up Ready ® soybean environments that were lacking in alternative vegetation which may serve as a habitat for prey species when aphids are not present (Ostman et al. 2001). Landscape manipulation is the key to increasing carabid numbers.

Lyon and Scanlon (1987) suggested the use of low growing buffer plants between forest edge and crop field to limit yield loss from deer consumption. They did not specify which type of plants to use as a buffer, perhaps because there was a potential for using plants that are undesirable or offensive to deer, or plants that deer are attracted to. Many home gardeners use "deer-resistant" plants as a tactic to avoid deer grazing on ornamental plants, this concept could be used on a large-scale to potentially deter deer from entering a certain area. A review of field margins in Europe indicates that deer are commonly attracted to leguminous strips near or around crop fields (Marshall and Moonen 2002). Conservation biological control in the form of landscape manipulation can serve a double purpose: habitat for carabids as well as a buffer crop to minimize deer grazing damage in a cash crop field.

1.6 Objectives

This thesis research examines the effects of perimeter plantings along edges of soybean fields on two different kinds of animals that potentially have very different impacts in this agricultural system: beneficial carabid beetle populations, and pest deer populations. The overriding objective of my research was to determine whether certain plants at field borders could concurrently encourage Carabidae populations while reducing the entry of deer into soybean fields, and thereby reducing damage to soybeans. If carabid beetle populations increased in certain perimeter treatments, I predicted this would result in lower incidence of soybean aphids (*Aphis glycines* Matsumura, a pest of soybean) and soybean crop damage. Several different perimeter plantings were tested, and effects on beetle diversity and abundance, soybean aphids, and deer damage were measured spatially and temporarily over the growing season.

1.7 Hypotheses

I hypothesize that soybean-field-edge plantings can:

1. reduce deer feeding on soybean by providing a deterrent and/or an alternative food source;

2. increase the abundance of predatory carabid beetles in soybean. I predict that soybean plots adjacent to field-edge plantings will have a higher density of beetles than plots without field-edge plantings due to carabid beetles preference for non-crop habitats;

3. reduce soybean soybean aphid density. I predict that a higher incidence of carabid beetles will result in a lower soybean aphid density due to the predatory nature of carabid beetles.

CHAPTER 2 MATERIALS AND METHODS

The experimental design for 2012 consisted of multiple treatments within a perimeter area. The design was modified for 2013 by reducing the number of treatments and increasing the plot size. The change was based on results from 2012 which indicated that the legume + grass treatment was a favourable environment for carabids as well as a suitable plant combination to act as a trap-crop for white-tailed deer. There were no significant effects of perimeter planting type on deer damage to soybean, so instead of aiming to repel deer from the field altogether, a decision was made to use the field-edge planting as a trap-crop or push-pull tactic to pull deer away from the soybeans by providing a palatable substitute that is close to the forest-edge.

2.1 2012 Experiment

Experiments were conducted at four sites during the summer of 2012, all located in central Nova Scotia: one site in Onslow (longitude: 45.390, latitude: -63.138), two sites in Beaver Brook (longitude: 45.303, latitude: -63.419; longitude: 45.273, latitude -63.426), and Balfron (longitude: 45.642, latitude: -63.263). All sites had mixed forest bordering at least two sides of the field, and two of the sites contained riparian zones. For all sites, each experimental unit (perimeter planting plot) was 20 m long x 4 m wide.

The experiment was established in randomized block design with four or five treatments, depending on the site. Treatments were chosen based on literature review, and common home-gardening techniques for contending with white-tailed deer. Three treatments were picked for their potential to repel deer: a deer resistant wildflower mix, mixed herbs, and orchard grass. There was a treatment containing clover and alfalfa which was intended as a distraction or alternative food source, and finally a soybean control.

The site in Onslow (McCurdy's) was previously planted with perennial forage, and did not contain any riparian areas. The field had an experimental strip planted along the Southern edge, bordering a wooded area (Appendix 2). The strip consisted of two blocks, with five treatments:

1. orchard grass (*Dactylis glomerata* variety: Crown Royal)
2. orchard grass + alfalfa (*Medicago sativa* variety: Starbuck) + red clover (*Trifolium pretense* variety: Tempus)
3. deer-resistant herbs: dill (*Anethum graveolens)*, summer savory (*Satureja hortensis)*, sage (*Salvia officinalis*), lemon balm (*Melissa officinalis*), bee balm (*Monarda*) , and parsley (*Petroselinum crispum*)
4. deer-resistant flower mix ("Downeast mixture" wildflowers, which includes: Blanket-flower, Yarrow, Dwarf Cornflower, Wallflower, Lance-Leaved Coreopsis, Floxglove, Purple Coneflower, Baby's Breath, Dense Blazing Star, Butter and Eggs, Scarlet Flax, Evening Primrose; "Annual Surprise Mixture", which includes African daisy, Baby Blue-Eyes, California Poppy, Creeping Daisy, dwarf Godetia, dwarf Plains Coreopsis, Five-Sport, Rocket Larkspur, Spurred Snapdragon, Sweet Alyssum (See Appendix 1 for latin names of all "Downeast" and "Annual surprise" mixture cultivars); *Centaurea cyanus* ("Polka Dot"); *Coreopsis* ("Early Sunrise"); *Calendula* ("Fiesta Gitana"); *Gaillardia*,

Zinnia (“Pompon”); *Echinacea* (“Primadona Deep Rose”); and *Papaver* (“Mission Bells Mix”)

5. soybean (*Glycine max*) as a control.

Soybean, alfalfa and clover seeds were purchased from Truro Agromart in Onslow, NS, and supplied by Mapleseed ™ Lindsay, ON. Orchardgrass seed was purchased from Co-Op Atlantic in Truro, NS. Wildflower and herb seeds were purchased from Vesey’s Seed, PE, Canada.

One site in Beaver Brook (Yuill’s) (Appendix 2) was previously planted with corn, did not contain any riparian areas, and consisted of two fields, each with one block planted along the western edge of the field, bordering a mixed forest. Each block contained four treatments: (1) orchard grass, (2) orchard grass + alfalfa + clover, (3) deer-resistant herbs (as listed above), and (4) a soybean control.

The second Beaver Brook site (Burrow’s) (Appendix 2) contained two riparian zones. It was previously planted with corn and consisted of three blocks, each with four treatments: (1) orchard grass; (2) orchard grass + alfalfa + red clover; (3) deer-resistant herbs; and (4) deer-resistant flower mix (as listed above). Blocks were situated along north, south, and west sides of the fields – near forest edges. The remaining field margins were seeded with orchard grass as opposed to soybean as the field edges were riparian areas and it is recommended that a buffer zone of perennial grasses be placed between riparian zones and crop fields (Schultz et al. 2004). The orchard grass plots at this site were considered control plots, as perennial grasses are used for buffer zones in fields with riparian zones that may not be seeded to the edge with soybean. The east side of the field was bordered by a busy road and was seeded with soybean to the edge.

The Balfron site (Baillie's) (Appendix 2) was previously planted with perennial forage and contained riparian zones. The field had three blocks, each with four treatments (the same as the second Beaver Brook site). The blocks were situated along the east, west, and south sides of the field, which were surrounded by woods and a brook. The remaining field margins were seeded with orchard grass on all sides. Orchard grass plots were used as control plots in this field due to presence of riparian zones. Field maps of all sites are presented in Appendix 2.

2.2 2013 Experiment

The experimental design for year two of the project was a randomized complete block design with two treatments. The treatments were chosen based on trends and observations from 2012. The deer seemed to be attracted to the legumes in the red clover + alfalfa + orchard grass plots and there was a trend toward higher beetle captures near the same plots. The two treatments used were: (1) orchard grass (*Dactylis glomerata* variety: Okay) + alfalfa (*Medicago sativa* variety: Genoa) + red clover (*Trifolium pretense* variety: Belle); and (2) a soybean control. All seeds were purchased from Truro Agromart in Onslow, NS, supplied by Mapleseed ™ Lindsay, ON. There were three sites and each site had 4 blocks.

The experimental fields were established at three sites in the summer of 2013. Two sites were located in Beaver Brook (longitude: 45.306, latitude: -63.419; longitude: 45.255, latitude: -63.432) and one site was located in Old Barns (longitude: 45.346, latitude: -63.419), both in Nova Scotia. All sites had mixed forest bordering at least two sides of the field and there were no riparian zones. For all sites, each experimental plot was 80 m long x 4 m wide.

The first site in Beaver Brook (Yuill's) (Appendix 3) consisted of two fields in close proximity (~ 600 m apart) that were previously planted with corn. One field had two blocks planted along the northern field-edge, and the other field had two blocks planted along the south-western field-edge. All plantings were adjacent to wooded areas.

The second Beaver Brook site (Burrow's) (Appendix 3) was previously planted with corn and consisted of one large field with two blocks planted along the south-west field-edge and two blocks planted along the north-east field-edge, both adjacent to wooded areas.

The third site was in Old Barns (McCurdy's) (Appendix 3) and consisted of one field with two blocks planted along the eastern field-edge and two blocks along the western edge, both bordering wooded areas.

For all sites, the plots containing soybeans were considered control treatments. Field maps of these sites are presented in Appendix 3. Figure 2.1 shows a clover + alfalfa + orchard grass perimeter plot at McCurdy's (Appendix 3).

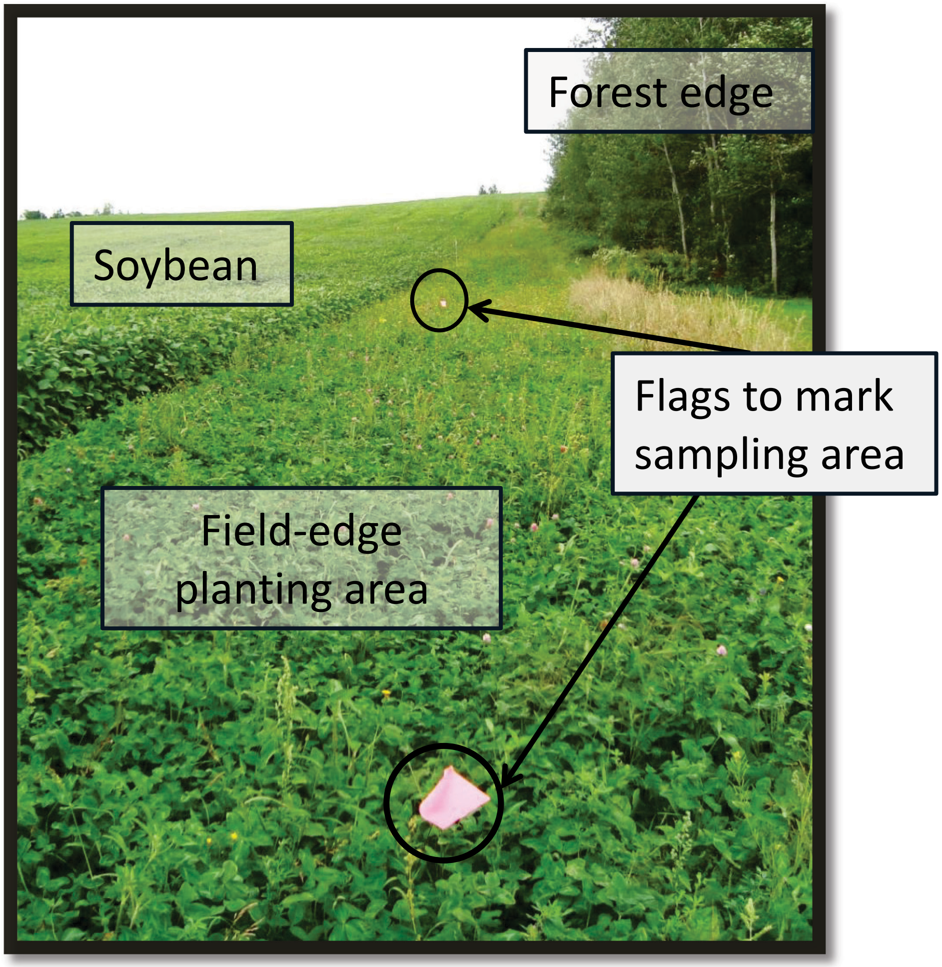

Figure 2.1. Field picture of red clover + alfalfa + orchard grass perimeter planting showing sampling area, forest and field-edges. Old Barns, Nova Scotia, Aug. 2013.

2.3 Seeding Rates for Treatments

All seeding was done with 15 cm row spacings, using a Tye® No-Till Seeder. Cultivars for all plant types are listed in Experimental Design (sections 2.1 and 2.2), above. In 2012: orchard grass was seeded at a rate of 14 kg ha^{-1}; orchard grass and legume mixture (36% alfalfa, 28% red clover, 36% orchard grass) was seeded at a rate of 22.5 kg ha^{-1}; herb mixture was seeded at a rate of 55 kg ha^{-1}; wildflowers were seeded at a rate of 21 kg ha^{-1} and the soybeans were seeded at a rate of 80 kg ha^{-1}. Seeding for

2012 was done on 15 May (Beaver Brook), 16 May (Balfron) and 12 June (Onslow). In 2013, orchard grass alfalfa and red clover mixture (36 % orchard grass, 36 % alfalfa, 28% red clover) was seeded at a rate of 32 kg ha^{-1}, and the soybeans were seeded at a rate of 80 kg ha^{-1}. Seeding for 2013 was done on 20 May (Yuill's), 6 June (McCurdy's) and 7 June (Burrow's).

2.4 Data Collection

2.4.1 Deer Presence and Soybean Damage

2012 Experiment

Deer presence and consumption of plants was estimated once every two weeks via visual counts and assessment of deer tracks or trails, and plant material removal. A section measuring 10 x 1 m was marked within the field-edge planting (0 m) and along a transect at 1, 6, and 20 m from each plot into the soybean field. At each section there were counts for deer damage to plants, and deer presence (which consisted of deer tracks or trails). Deer grazing damage to plants was identified by their unique biting pattern: deer only have teeth on their lower jaw, so plants that have been grazed by deer are clean-cut on the bottom and torn at the top (Fig 2.2 and 2.3) (Anonymous 2006). The tracks were quantified by counting the number of individual hoof prints along a marked section (Figure 2.4). Tracks were counted until the canopy coverage became too dense (before Aug 3), then trails through soybean canopy were counted at the marked sections. The deer data collection also consisted of a visual assessment of deer-inflicted plant damage, quantified by counting the number of damaged plants in a single 10 m row. At the end of the season, biomass of plants was measured by collecting two 0.25 m^2quadrats of plant material from each marked section along transects, and thereafter determining dry weight in the laboratory.

Figure 2.2. Deer grazing damage to red clover. Red circles show where deer have grazed. Nova Scotia, 2012.

Figure 2.3. Deer grazing damage to soybean plants. Red oval shows where deer have grazed. Nova Scotia, 2012

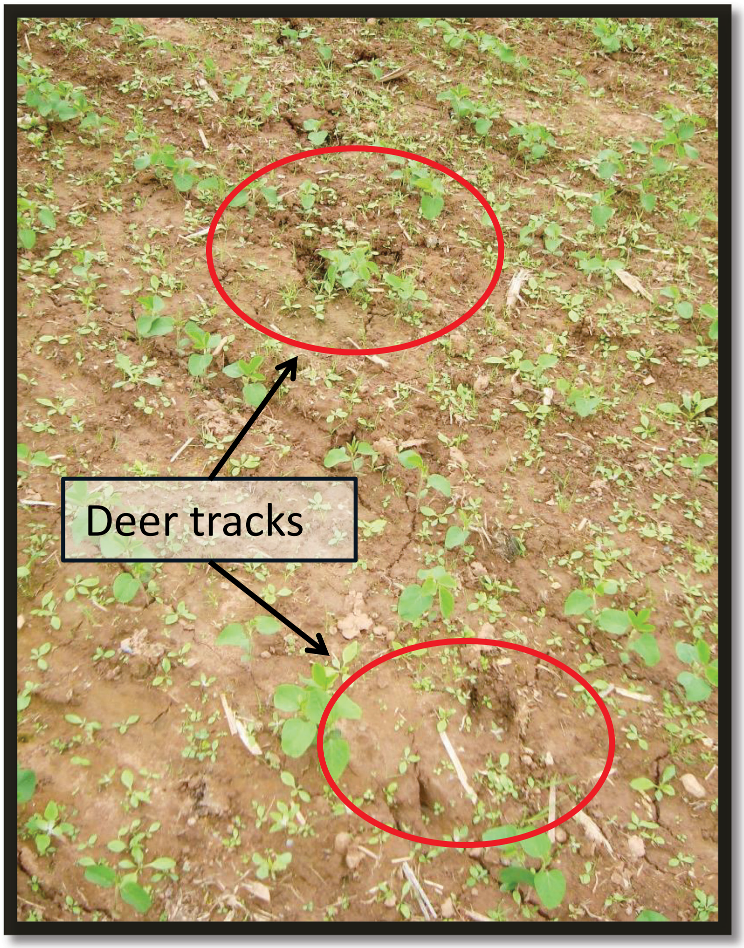

Figure 2.4. Deer tracks in soybean field. Nova Scotia, 2012.

2013 Experiment

Data collection for deer presence and damage in 2013 was similar to 2012, however the plots were larger in 2013 and thus the marked sections for data collection were 20 x 1 m. The transect collection areas were marked within the plot (0 m) and at 6 and 20 m into the soybean field. Damage to soybean plants was quantified in the same way as 2012. Deer tracks were quantified in the same way as 2012 for the first two sampling dates, but the plant coverage became too thick, making it difficult to see tracks, and the trails became difficult to identify within the crop field as it was hard to determine if the trails were made from people doing data collection or by deer. Deer trails were quantified at the forest edge adjacent to treatment plots as opposed to within the field. Biomass collection was done using the same method as 2012 but pod yield biomass was added to the laboratory analysis. Visual observations with binoculars for deer browsing behavior were conducted on two separate occasions at Yuill's site from ~19:30-21:00 in July and August.

2.4.2 Insect counts

In 2012 and 2013, aphid abundance on soybeans was estimated once every two weeks, starting July until mid-September, along the same transect data collection areas marked for deer data collection. In each area, the number of aphids on the leaf second from the top was counted on three randomly selected soybean plants per transect location. This sampling method was adapted from four different methods from: National Soybean Research Laboratory in co-operation with University of Illinois (Anonymous 2012b), Agriculture and Agri-food Canada Pesticide Risk Reduction Program (Anonymous 2012c), and Iowa State University Extension Factsheet on Soybean Aphids in Iowa (Rice et al. 2007). Soybean aphid specimens were collected and sent to Guelph University (Guelph, ON) for genetic sequencing and identification to confirm species (Maw 2013)

Also, in 2012 and 2013, carabid beetle abundance and diversity in soybean fields was measured once every two weeks using pitfall traps. Traps were installed when orchard grass height was less than 5 cm. One trap was installed within each treatment plot, and at 6 and 20 m from the edge of each plot. Pitfall traps consisted of two 450 mL cups snugly embedded in the field so that the top of the cup was flush with the soil (Figure 2.5). Lids were used to open or close traps for beetle collections. Traps were filled halfway with a brine solution containing 1.5% table salt to kill and conserve beetles, with 0.25% unscented dish soap to break surface tension. Traps were activated for a 48 h period once every 2 weeks, and beetles collected from traps were placed in labeled containers containing 70% ethanol and returned to the laboratory for pinning and identification. Identification was carried out using identification keys found in: "The ground-beetles (Carabidae, excl Cicindelinae) of Canada and Alaska, Part 2", written by Lindroth (1961, 1963, 1966, 1968, 1969a, 1969b).

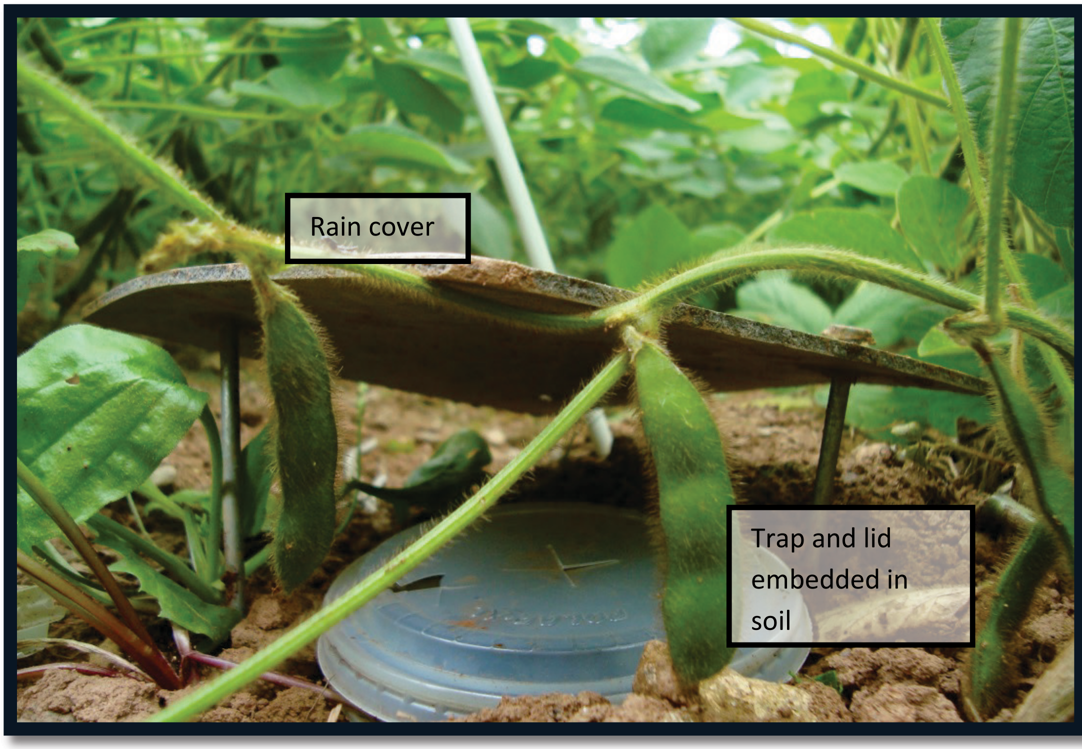

Figure 2.5. Pitfall trap in soybean field with rain cover and lid to activate and deactivate trap. Nova Scotia, 2013.

2.5 Data Analysis

All analyses were carried out using Proc Mixed in SAS version 9.3. Treatment was considered a fixed effect and site*block was considered a random effect. Repeated measures analysis with distance as the repeated measure was used for data that met assumptions of analysis of variance (ANOVA) (normality, constant variance, and independence of residuals). Fisher's protected LSD (least significant difference method) ($\alpha = 0.05$) was the method used for means separation. Data that failed to meet ANOVA assumptions were analyzed using Kruskal-Wallis tests. Unless stated otherwise, all means are reported +/- standard error of the mean (SEM). Correlation analyses were performed using Proc Corr in SAS.

2.5.1 Deer Presence and Soybean Damage

Deer presence (tracks and trails) and plant damage data from all dates in the 2012 field season were analyzed separately, using Kruskal-Wallis tests, as the residuals were not normally distributed and was not constant variance. Data transformations failed to induce normal distributions of errors and constant variance.

Deer presence (tracks and trails) data from all sampling dates in 2013 were analyzed using repeated measures ANOVA (Proc Mixed). Data from each date were analyzed separately and the most appropriate covariance structure was selected based on lowest scores for AICC (corrected Akaike Information Criteria) and BIC (Schwarz's Bayesian Information Criteria) (Wang and Goonewardene 2004). The covariance structure best suited to data from all dates in 2013 was ante-dependence (1).

In 2013, plant damage data for days 213, 227, 239, and 253 were analyzed using repeated measures analysis (Proc Mixed). The covariance structure selected for days 213 and 253 was "ante-dependence (1)"; the covariance structure selected for day 227 was "toeplitz"; the covariance structure selected for day 239 was "compound symmetry". Damage data from day 197 were analyzed using the non-parametric Kruskal-Wallis tests as the residuals were not normally distributed and constant variance was not achieved.

2.5.2 Beetle Abundance

Beetle abundance data for all sampling dates in 2012 were analyzed using repeated measures ANOVA (Proc Mixed). Square root transformations were required to induce normality of residuals in data sets from July 20, August 3 and August 15. Beetle abundance data from all sampling dates in the 2013 field experiment were analyzed using Kruskal-Wallis tests as the residuals failed to meet ANOVA assumptions.

2.5.3 Aphid Abundance

Aphid-count data from all sampling dates in the 2012 field experiment were analyzed using Kruskal-Wallis tests as the assumptions necessary to perform ANOVA were not met. Aphid-count data from all sampling dates in the 2013 field experiment were analyzed using repeated measures ANOVA (Proc mixed). The covariance structure used for data analysis on day 239 was "ante-dependence (1)". The data from day 253 was subjected to a square root transformation in order to fulfill ANOVA assumptions. The covariance structure used for this data set was "compound symmetry".

Non-parametric correlation analysis was used for Aphid vs Beetle counts in 2012 and 2013 as the data failed to meet the assumptions.

CHAPTER 3 RESULTS AND DISCUSSION

3.1 General Observations

Findings from the 2012 field season showed no differences in deer grazing damage or deer presence among treatments. Highest Carabidae captures were at field edge and there was no effect from field-edge planting treatment on captures. The lack of significant effect from field-edge planting treatment led to an increased plot length, decreased number of treatments, and increased replications of treatments. Key findings from 2013 showed greatest deer foraging on soybean plants close to field-edge with significantly less browsing damage to soybean plants adjacent to legume + orchard grass perimeters. Deer consumed the legumes from perimeter plantings, and the soybean pod biomass from areas adjacent to legume + grass perimeter was significantly higher than areas adjacent to soybean perimeter planting. More carabid beetles were captured in areas adjacent to legume + grass perimeter planting.

3.2 Deer Presence and Deer Related Soybean Damage

3.2.1 2012 Experiment

Perimeter treatments for 2012 included: soybean; mixed herbs; wildflowers; orchard grass; and orchard grass + alfalfa + red clover. There were no significant effects of treatment or distance on deer presence as measured by counting deer tracks and trails throughout the 2012 growing season (Table 3.1). Sampling dates before Aug 3, 2012 had too many “0” counts to perform a statistical analysis.

Table 3.1. Effect of border treatment perimeter plantings around soybean fields and distance into field on presence of white-tailed deer, Nova Scotia, 2012 (Kruskal-Wallis tests).

Factor	*df*	Sample Date							
		Aug 3		Aug 15		Aug 30		Sep 12	
		X^2	***P***	X^2	***P***	X^2	***P***	X^2	***P***
Treatment	4	3.14	0.5342	4.53	0.3387	2.10	0.7175	1.88	0.7581
Distance	2	2.00	0.3679	3.01	0.2220	2.30	0.3169	0.10	0.9496

Browsing damage to soybean plants by deer was not significantly affected by distance or border treatment on most sampling days (Table 3.2), but soybean damage from deer was greater at a distance of 6 m on Aug 15 (Figure 3.1). On that date, damage from deer was more than four times greater at 6 m than at 1 m, while relatively intermediate soybean damage was observed at 20 m from edge of fields. The reason for increased damage at the 6 m distance compared to 1 m may be due to higher shading at forest edge which may lead to poor soybean plant growth and potentially less palatable plant material as the leaves would be smaller and the plants would be shorter. Visual observations throughout the field season suggested that soybean plants close to the forest edge may have been smaller than soybean plants that were in full sun. Colligan et al. (2011) found that deer seemed to prefer taller plants. If there was shading of plants near the forest edge which caused them to be shorter, it may have affected the deer's grazing preference. Rogerson (2005) found overall higher deer browsing on soybean within 5 and 15 m from a forest edge than at 35 m into the soybean field. This is likely due to the natural instinct of deer to graze close to forest-edge where there is protection and shelter.

Table 3.2. Effect of border treatment perimeter plantings around soybean fields and distance into field on grazing damage to soybean plants caused by white-tailed deer, Nova Scotia, 2012 (Kruskal-Wallis tests).

Factor	*df*	Sample Date							
		Aug 3		Aug 15		Aug 30		Sep 12	
		X^2	P	X^2	P	X^2	P	X^2	P
Treatment	4	2.51	0.6419	3.90	0.4201	4.80	0.3082	0.92	0.9224
Distance	2	1.06	0.5897	7.79	**0.0204***	3.00	0.2226	1.49	0.4741

* P-values < 0.1 bolded to show significance

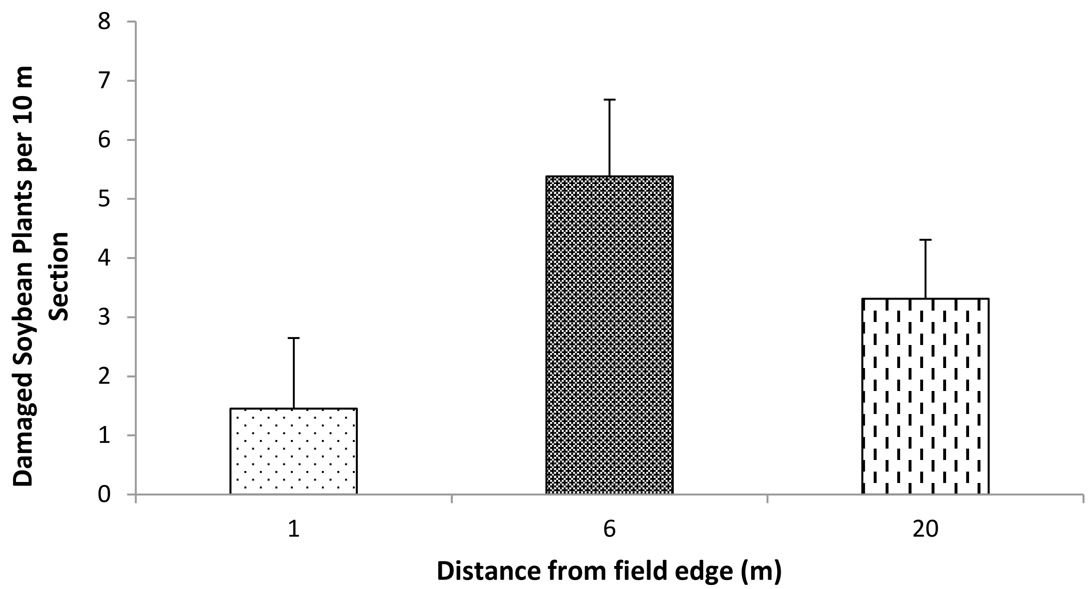

Figure 3.1. Mean damage (+/- SEM) by deer to soybean plants (Nova Scotia, 15 Aug, 2012) at different sampling distances from the field edge. Effect of border treatment was not significant, so captures were combined across treatments.

Mean soybean plant biomass was significantly lower at the 1 m sampling area (Table 3.3; Figure 3.2) than at 20 m into soybean field. Both the 1 m and 20 m sampling areas were not significantly different from the 6 m sampling area dry weight plant biomass harvested. There were no significant effects of treatment or the interaction of treatment and distance on soybean biomass (Table 3.3). Similarly, Rogerson (2005) harvested soybean plants and found that crop biomass 25 m into fields was significantly greater than at 5 m from the field edge. This type of result would be expected if deer browsing rates were higher at the forest edge. However, deer browsing damage to soybean plants was not significantly higher at the forest-edge (Table 3.2). In fact, browsing damage on one sampling date was higher at 6 m than at the forest edge. As suggested above, shading from the forest may have led to reduced crop growth in the field-edge area and subsequently lower plant biomass. However, this was only seen on one sampling date. Rogerson et al. 2014 found that soybean yield was lower close to forest edge, as opposed to areas 20 m into soybean field, and that there was no relationship between lower yield at forest edge and deer grazing damage. As there was no data collected regarding shading at the forest edge, it is difficult to determine if shading was actually the cause of increased grazing at 6m into the crop field on one sampling date.

Table 3.3. Effect of field edge treatment and distance into fields on soybean plant biomass, Nova Scotia, 2012 (mixed model ANOVA).

Factor	*df*	*F*	*P*
Treatment	4	0.86	0.5058
Distance	2	5.19	**0.0099***
Treatment x Distance	8	0.86	0.5582

* P-values <0.1 bolded to show significance

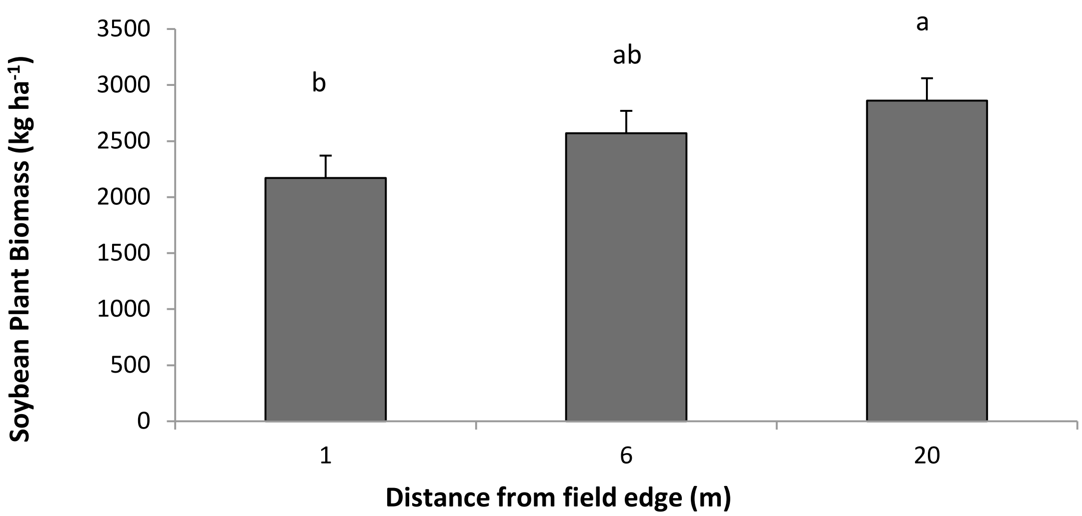

Figure 3.2. Mean above-ground soybean dry matter biomass (+/- SEM) for 3 distances from field-edge (Nova Scotia, 2012). Effect of border treatment was not significant, so captures were combined across treatments. Bars with different letters above them are significantly different within each date (Fisher's Protected LSD, α = 0.05).

3.2.2 2013 Experiment

On July 16, there was significantly higher deer presence (deer tracks) 0 m from the field edge than any other distance (Table 3.4; Figure 3.3). After July 16, soybean plant foliage was too thick to see the soil and thus counting tracks was discontinued. This measurement was replaced by counting of deer trails at the forest edge instead

(Table 3.5). Deer trails at the forest/field edge on Aug 27 were greater adjacent to control (soybean) plots, with a mean of 11.42 (± 0.79) trails per sampling area compared to a mean of 8.08 (± 0.79) trails adjacent to legume + orchard grass plots.

Table 3.4. Effect of border treatment perimeter plantings around soybean fields and distance into field on presence of white-tailed deer, Nova Scotia, 2013 (mixed model ANOVA).

Factor	*df*	Sample Date			
		Jul 2		Jul 16	
		F	***P***	***F***	***P***
Treatment	1	1.81	0.1942	0.01	0.9275
Distance	2	2.18	0.1432	6.26	**0.0069***
Treatment x Distance	2	0.04	0.9613	1.05	0.3673

*P-values <0.1 bolded to show significance

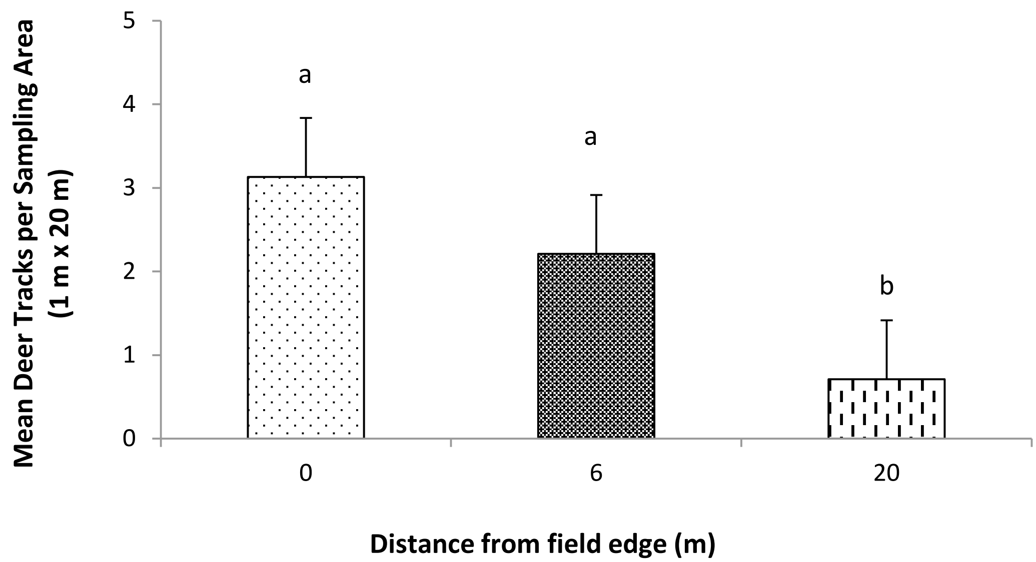

Figure 3.3. Mean deer tracks (+/- SEM) adjacent to perimeter planting for 3 sampling distances with treatments combined (Nova Scotia, 16 Jul, 2013). Bars with different letters above them are significantly different (Fisher's Protected LSD, α = 0.05).

Table 3.5. Effect of border treatment perimeter plantings around soybean fields and distance into field on presence of white-tailed deer, Nova Scotia, 2013 (mixed model ANOVA).

Factor	*df*	Sample Date							
		Aug 1		Aug 15		Aug 27		Sep 10	
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Treatment	1	0.25	0.6198	1.55	0.2385	8.95	**0.0067***	1.29	0.2808

*P-values <0.1 bolded to show significance

Deer trails leading into/out of the forest (at field-edge) were likely established before planting of soybeans, in which case the location of the trails (close to soybean perimeter vs. close to legume + orchard grass perimeter) would have no relationship with the actual foraging preferences of the animals. However, the number of trails counted varied among sampling dates, which indicated that at least some of the trails were established at the forest edge after planting. I performed a visual observation of deer browsing behavior at dusk (from ~ 7:30 pm until dark) at a single site on two occasions and observed that deer began browsing close to forest edge and slowly wandered further into the fields. They appeared to graze multiple plants rather than fully consume any single plant and they generally did not venture more than 30 m into the soybean fields. My observations are similar to Lyon and Scanlon (1987), who observed 90% of deer within 50 m of forest edge and 50% of deer sighted within 10 m from forest edge.

The relationship between deer damage to soybean plants and the experimental factors (treatment and distance) was significant on most sampling dates (Table 3.6). On July 16 there was a marginally significant effect of treatment on soybean plant damage; sampling areas adjacent to legume + grass plots had 4 times less damage to plants than sampling areas adjacent to soybean plots with 0.19 (± 0.07) damaged plants per sampling area associated with legume + grass and 0.94 (± 0.25) damaged plants for areas

Table 3.6. Effect of border treatment perimeter plantings around soybean fields and distance into field on grazing damage to soybean plants caused by white-tailed deer, Nova Scotia, 2013 (Kruskal-Wallis tests for 16 Jul; mixed model ANOVA for all other dates) .

Factor	*df*	Sample Date									
		Jul 16		Aug 1		Aug 15		Aug 27		Sep 10	
		X^2	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Treatment	1	3.36	0.0607	10.34	0.0059	21.75	0.0005	5.69	0.0026	13.04	**0.0038***
Distance	2	1.08	0.5813	1.45	0.2538	9.99	0.0004	37.54	< 0.0001	1.49	0.2450
Treatment x Distance	2	N/A	N/A	9.82	**0.0008***	5.53	**0.0084***	2.59	**0.0865***	1.81	0.1838

*P-values <0.1 bolded to show significance

associated with soybean perimeter. Significant interactions of border treatment and distance into fields were found on August 1 and August 15. On August 27 the interaction effect was marginally significant and on September 10, the effect of distance was significant. On Aug 1, soybean plant damage at the 0 m and 6 m sampling areas adjacent to legume + grass plots was significantly lower than 0 m and 6 m sampling areas adjacent to soybean plots, but damaged plants at the 20 m sampling area adjacent to legume + orchard grass plots was not significantly different from 20 m sampling area adjacent to soybean plots (Figure 3.4). On August 15 the 0 m and 6 m legume + grass sampling area had significantly lower damaged plants than the 0 m soybean sampling area. The 6 m sampling areas for legume + orchard grass had significantly lower damaged plants than 6 m sampling area for soybean (Figure 3.5).

The number of damaged plants at the 0 m legume + grass sampling area was greater than the 6 m legume + grass sampling area, suggesting that deer were browsing on the legume + grass perimeter planting may have led to decreased browsing on soybean plants adjacent to the perimeter planting. On August 27, the interaction effect was marginally significant with the damage rating for soybean at 0 m greater than the legume + orchard grass 0 m sampling area, but the damage rating for 6 m soybean was not significantly different than 6 m sampling area associated with legume + orchard grass (Figure 3.6). On September 10 there was no interaction effect but there was significantly more deer related damage associated with soybean plots with 15.22 (± 1.23) damaged plants per area for soybean and 11.69 (± 1.15) for legume + grass.

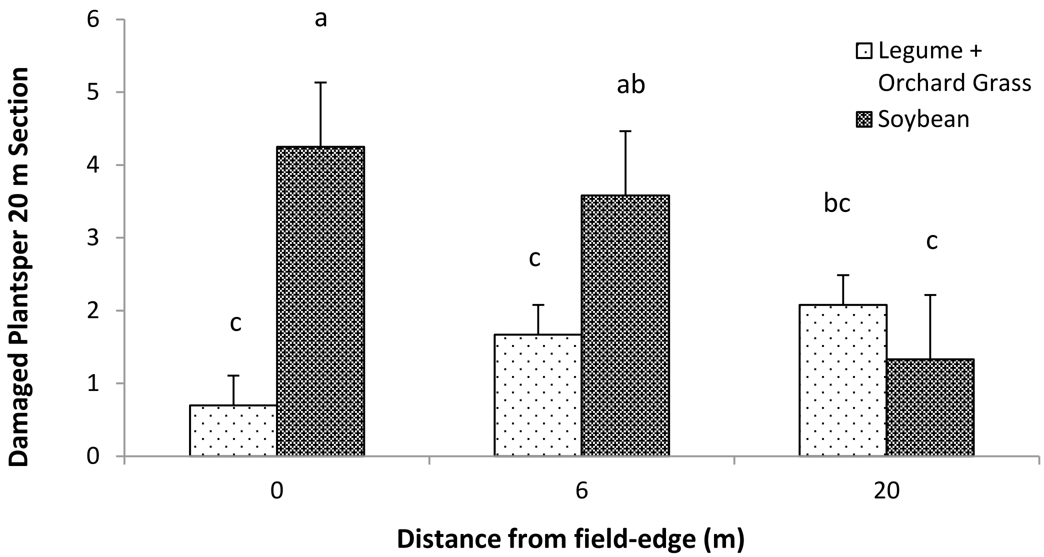

Figure 3.4. Mean number of plants (+/- SEM) damaged by deer for different sampling distances from the field edge for two different perimeter planting treatments (Nova Scotia, 1 Aug, 2013). Bars with different letters above them are significantly different (LSD means separation, $\alpha = 0.05$).

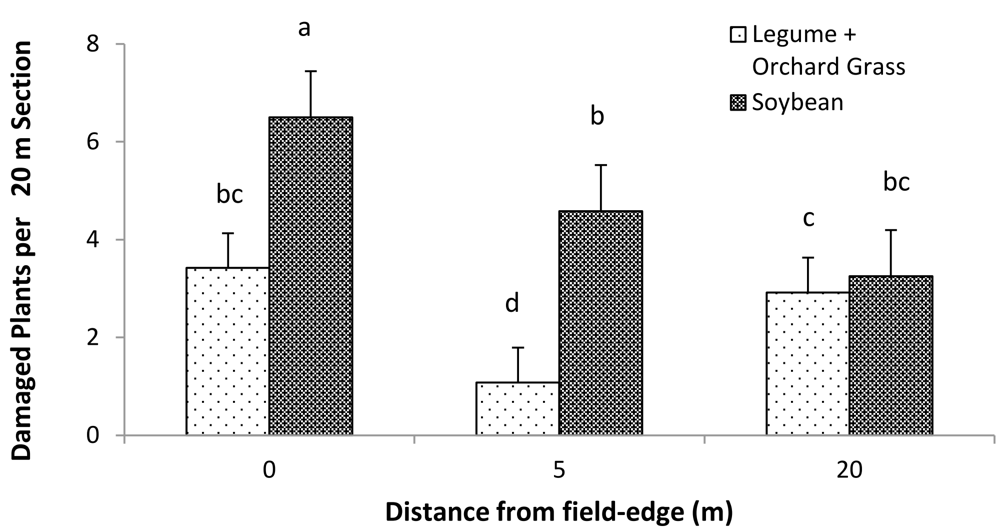

Figure 3.5. Mean number of plants (+/- SEM) damaged by deer for different sampling distances from the field edge for two different perimeter planting treatments (Nova Scotia, 15 Aug, 2013). Bars with different letters above them are significantly different (LSD means separation, $\alpha = 0.05$).

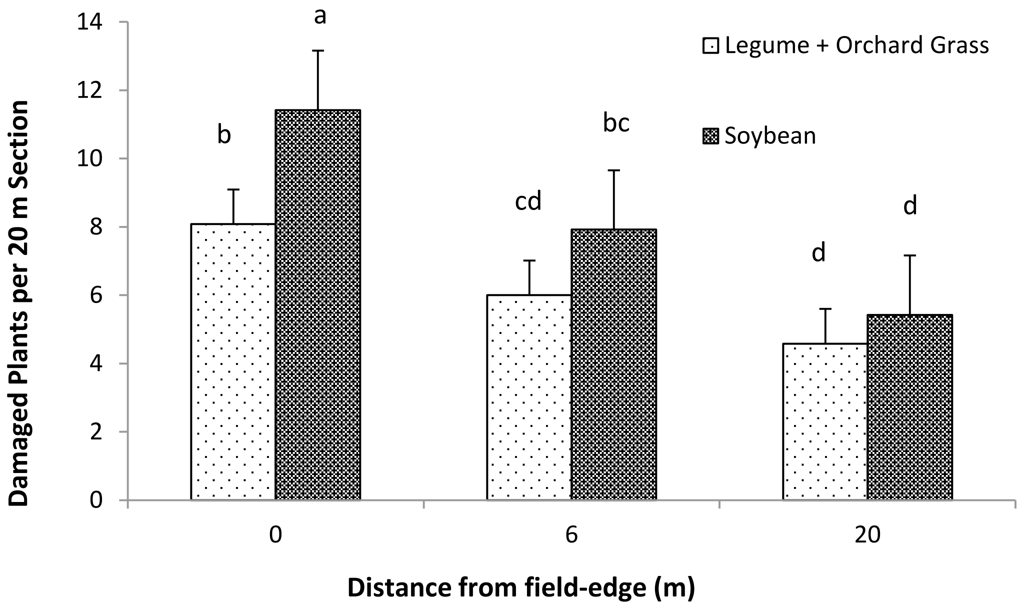

Figure 3.6. Mean number of plants (+/- SEM) damaged by deer for different sampling distances from the field edge for two different perimeter planting treatments (Nova Scotia, Aug 27, 2013). Bars with different letters above them are significantly different (LSD means separation, $\alpha = 0.05$).

Greater soybean damage was consistently observed at 0 m from legume + orchard grass perimeter plots than 6 m and 20 m away from the perimeter into field. This is promising for farmers as the legume plots were intended as a trap crop to pull deer away from the main crop and minimize their browsing on soybean. Marshall and Moonen (2002) reviewed many studies on field margins and found that deer were commonly attracted to leguminous margins. Similarly, a government fact sheet regarding diets of white tailed deer stated that deer prefer legumes over grasses and that alfalfa is a highly desired forage legume for deer (Klein 2013). The legume + orchard grass perimeter planting treatment included alfalfa as one of the legumes and thus represents a good alternative to soybeans for deer. Although deer have been known to avoid orchard grass, which was part of the legume mixture, they will eat around the orchard grass if there is something desirable in the mix (Hall and Stout 1999).

Whole-plant biomass did not differ between treatments or distances in 2013 (Table 3.7), which may suggest that deer browsing damage did not have an impact on plant biomass. Rogerson et al. (2014) studied the effect of protecting soybeans from deer on yield and found that the yield of protected soybean plants was no higher than the yield of soybean plants that were browsed by deer. The whole-plant biomass is not equivalent to yield as the beans (pods) are the only part of the plant that is harvested.

Table 3.7. Effect of field border treatment and distance from field edge on soybean plant biomass, Nova Scotia, 2013 (mixed model ANOVA).

Factor	***df***	***F***	***P***
Treatment	1	0.56	0.4877
Distance	1	0.14	0.7128
Treatment x Distance	1	0.26	0.6136

Soybean pod biomass (equivalent to soybean yield) was greater in areas adjacent to the legume + orchard grass perimeter planting (marginal significance) with a mean pod dry weight of 2599 (±400) kg ha^{-1} compared to 1913 (±300) t ha^{-1} in areas adjacent to soybean plots (Table 3.8).

Table 3.8. Effect of field border treatment and distance from field edge on soybean pod biomass, Nova Scotia, 2013 (mixed model ANOVA).

Factor	***df***	***F***	***P***
Treatment	1	5.33	**0.0682***
Distance	1	0.74	0.3945
Treatment x Distance	1	2.29	0.1395

*P-values <0.1 bolded to show significance

The discrepancy between whole plant and pod biomass measurements could indicate that deer were grazing more heavily on soybean pods as opposed to leaves. Visual observations of damage to plants and of the deer grazing behaviours indicated that all plant material was being grazed but there were no measurements to determine the number of pods removed on grazed plants. Garrison and Lewis (1987) proposed that soybean plants can withstand as much as 67% defoliation before there is an effect on yield. The defoliation amount was not recorded in this study. deCalesta and Schwendeman (1978) determined that browsing damage during the first week after sprouting has the most impact on yield (pods/beans). The first week after sprouting was associated with sampling on day 197 and there was an average of 2 damaged plants per sampling area for sampling areas adjacent to soybean plots compared to approximately 0.5 damaged plants in sampling areas associated with legume plots. The higher damage ratings early in the season are consistent with pod biomass from the end of the season (lower biomass associated with soybean perimeter).

Results from 2012 differed from 2013 with regards to effect of treatments of soybean plants. While there was a significantly higher amount of deer inflicted soybean damage at distances closest to the field edge in 2012, there appeared to be no effect of treatment on deer inflicted soybean damage. In 2013 there was significantly more soybean browsing damage associated with the soybean perimeter planting (control) and there were treatment*distance interactions on certain dates. The number of treatments was lowered from five (2012) to two (2013) and the plot length was increased from 20 m (2012) to 80 m (2013). I believe that these changes to the experimental design resulted in the detection of significant differences between treatments as deer are large mammals and can cover a vast area while foraging.

3.3 Carabid Beetle and Aphid Abundance

3.3.1 2012 Experiment

In 2012, 1859 carabid beetles were captured between July 5 and August 31. *Pterostichus melanarius* and *Harpalus rufipes* were the most prevalent species, accounting for approximately 43 and 37 percent of all captures, respectively. These two species are very common in Nova Scotia (and Canada) and can be found in residential gardens, crop fields, grasslands, and forests. A complete list of all species is presented in Appendix 5. Carabid beetle abundance (inferred from captures) steadily increased throughout the growing season, with a decline of approximately 50% in abundance after August 15, as the total carabid beetle capture went from 580 (Aug 15) to 255 individuals (Aug 31) (Figure 3.7). Due to high rainfall and flooding events, there were no carabid beetles captured after August 31 (traps were activated but flooding led to fields being inaccessible), making it impossible to determine if abundance of carabid beetles in the soybean crop fields in my study would have steadily declined into the fall/harvest season. House and All (1981) found the greatest abundance of carabid beetles at the beginning of July and mid-September, and O'Neal et al. (2005) found greatest abundance of carabid beetles in highbush blueberry fields in August and September. Renkema et al. (2012) found that *P. melanarius* captures in Nova Scotia highbush blueberry fields declined from late July to late September, but does not mention other carabid species. The presence of carabid beetles in a crop field may be influenced by natural lifecycle peaks and other factors such as prey availability and canopy coverage (Varchola and Dunn 1999). The two most prevalent species, *H. rufipes* and *P. melanarius* are known to be predators of insects such as aphids and caterpillars (Firlej et al. 2013; Renkema et al. 2013; Carvalho et al. 2014). Caterpillar presence was not measured in this study, but the relationship between carabid beetle capture and aphid abundance is discussed below.

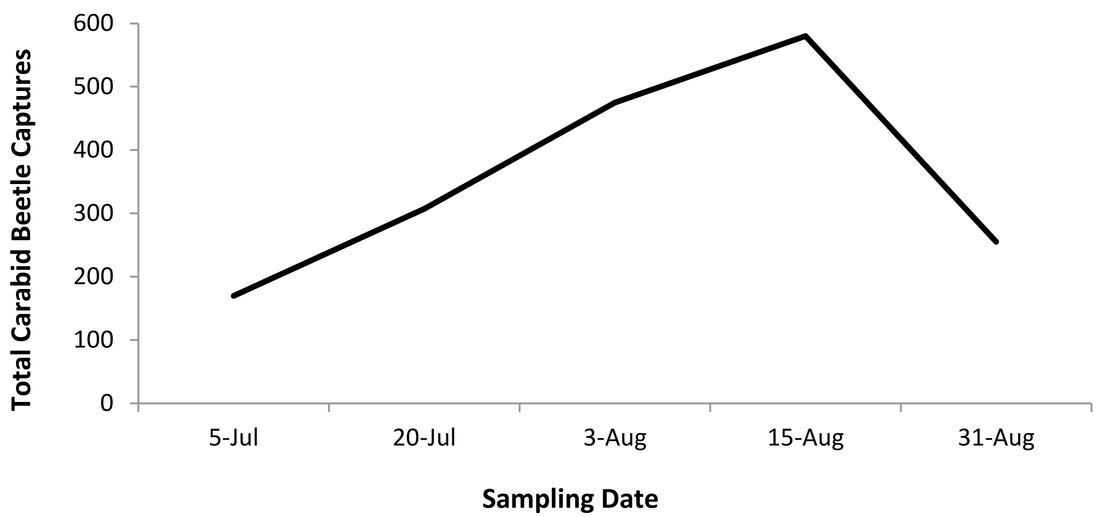

Figure 3.7. Total number of Carabidae captured in pitfall traps (n = 68 traps over 3 fields) placed in soybean fields, Nova Scotia, 2012.

There were no significant interaction effects from the experimental factors on carabid captures on any sampling dates. There was no effect of field-edge treatment, but the effect of distance was significant on three sampling dates (Table 3.9). More beetles were captured at forest edges (0 m distance) compared to areas further into the crop field on July 20, August 3, and August 15 (Figure 3.8). On July 20, carabid beetle captures at 0 m (closest to forest edge) were 3-fold greater than at 20 m; on August 3, carabid beetle captures at 0 m were double the amount captured at 20 m; and on August 15 the carabid beetle captures at 0 m were 8 times greater than at 20 m.

Cutler et al. (2012) found no effect of distance from forest edge into crop field on carabid beetle abundance, which is contrary to the findings of my study. Cutler et al. (2012) worked in lowbush blueberry fields in Nova Scotia, which are managed differently than most conventional crops as lowbush blueberries are wild and perennial, meaning tillage does not occur in the field. With conventional annual crops such as corn and soybean, the crop is removed and the field is left with no coverage for a period of the year, then disturbed by tillage and planting processes in the spring. This could be a reason for conflicting results between the two studies. O'Neal et al (2005a) found that carabid beetles were more abundant in highbush blueberry fields in areas that had plant coverage such as clover or ryegrass (where blueberry plants were not growing) as opposed to areas that had bare soil.

Table 3.9. Effect of field border treatment and distance from field edge on Carabidae captures in soybean fields, Nova Scotia, 2012 (mixed model ANOVA).

Factor	***df***	Sample Date									
		Jul 5		Jul 20		Aug 3		Aug 15		Aug 31	
		F	***P***	***F***	***P***	***F***	***P***	***F***	***P***	***F***	***P***
Treatment	3	0.32	0.8110	0.04	0.9875	1.34	0.3119	0.55	0.6548	0.96	0.4345
Distance	2	1.09	0.3576	9.90	**0.0009**	9.05	**0.0014**	4.56	**0.0177**	1.39	0.2732
Treatment x Distance	6	0.54	0.7743	0.81	0.5740	1.75	0.1536	1.52	0.2009	1.65	0.1803

*P-values <0.1 bolded to show significance

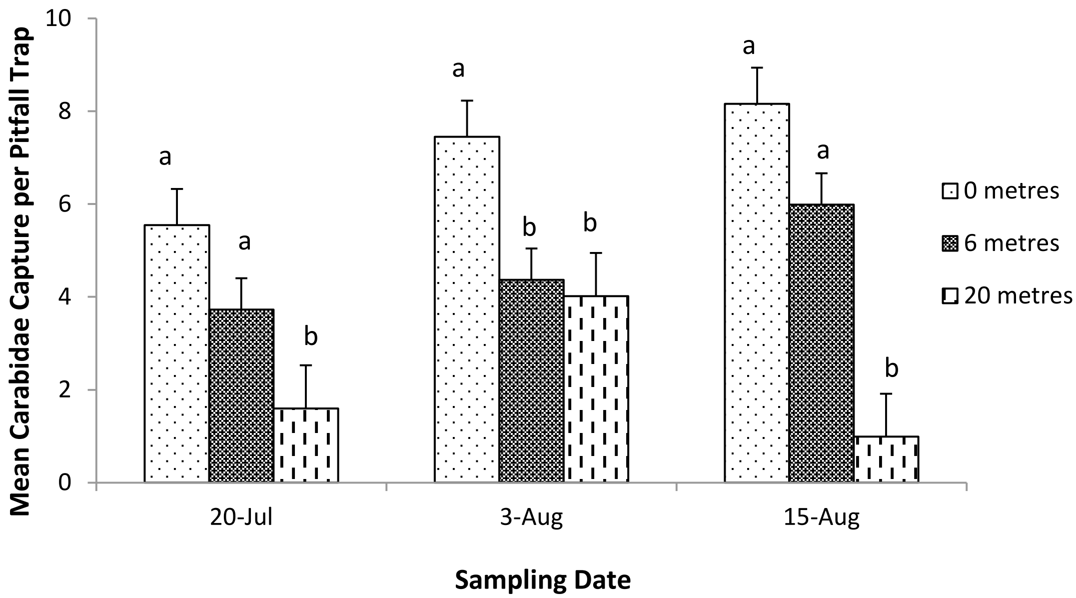

Figure 3.8. Mean (+/- SEM) Carabidae captures per trap in soybean fields (n= 68 traps in total, Nova Scotia, 2012) at different distances from field-edge on different sampling dates. Effect of border treatment was not significant, so captures were combined across treatments. Bars with different letters above them are significantly different within each date (LSD means separation, α = 0.05).

There were no significant effects associated with perimeter plantings. This could be a consequence of inadequate plot size, as carabids are active beetles capable of covering large areas. Baars (1979) found that Carabidae inhabiting a 1 ha area could cover up to 49 ha over the course of seven weeks. Wallin and Ekbom (1988) monitored carabids and found that they can travel at rates between 2 and 6.5 m^2 per hour. The field-edge planting plots for 2012 were 20 m long which may have been too short a distance to detect specific habitat preferences.

Carmona and Landis (1999) established refuge strips in cereal fields and found that the crop areas surrounded with refuge strips had no greater abundance of beetles than areas without refuge strips. They did find, however, higher capture rates of carabids within the refuge plantings compared to crop areas and concluded that highly attractive refuge strips may have a negative effect on the dispersion of beetles into crop fields. This may have also been the case with my study, as there were consistently higher captures of carabid beetles within the perimeter planting area than 6 m and 20 m into the crop field. The field-edge plantings had higher plant biodiversity and may have attracted a more desirable variety of insects for the carabids to prey on.

Aphid numbers in soybean fields were low throughout the summer and soybean aphids were only detected on August 31 and September 13. There was no significant effect of treatment or distance on number of aphids (Table 3.10). The correlation between beetle capture and aphid presence was not significant (P = 0.51; Spearman correlation coefficient = 0.0924).

Table 3.10. Effect of field border treatment and distance from field edge on number of soybean aphids (*A. glycines*) Nova Scotia, 2012 (Kruskal-Wallis tests).

Factor	*df*	Sample Date			
		Aug 31		Sept 13	
		X^2	P	X^2	P
Treatment	4	7.38	0.1169	4.10	0.3924
Distance	2	2.93	0.2311	0.09	0.9582

Aphid populations in crop fields are highly variable from year to year. Bahlai et al. (2010) noted a potential two-year cycle with one low year and one high year. In low years, there was no detection of aphids until after mid-July. It is possible that the low aphid counts in my fields were due to yearly fluctuations in aphid colonies. The low counts could also be due to lack of suitable primary host plants near the fields used for this study. Unfortunately, the sites used for 2013 were not the same so it was not possible to compare aphid counts from 2012 to 2013.

3.3.2 2013 Experiment

In 2013, 244 carabid beetles were captured, which was > 7.5-fold lower than total captures in 2012. The reason for this is unknown but the fields used in 2013 were not the same fields as 2012. Also, crop rotation and farming practices were different between fields and years, as they did not all belong to the same producer. The rainfall amounts differed greatly from summer 2012 to summer 2013. From April – September 2012 there was 732 mm of rain (70 mm in April, 61 mm in May, 60 mm in June, 58 mm in July, 157 mm in August, 326 mm in September), and April –September of 2013 saw a total of 542 mm of rain (76 mm in April, 62 mm in May, 173 mm in June, 92 mm in July, 30 mm in August, 109 mm in September) (Gov't of Canada, 2014). The difference in rainfall amounts in 2013 relative to 2012 may have affected carabid beetle abundance. Williams et al. (2014) studied the effects of decreased and increased soil moisture and precipitation on Carabidae communities and found that beetle abundance and Carabidae tribe richness were positively related to soil moisture and that plots with reduced precipitation (33 % less precipitation than average) had significantly less abundance and tribe richness than plots with average and increased (33% more than average) precipitation.

In 2013, there were eight species collected. The most abundant species were *H. rufipes* and *Anisodactylus sanctaecrucis,* representing about 33% and 29% of total captures respectively. *Pterostichus melanarius* was also prevalent, comprising about 15% of total captures. Total captures of Carabidae in 2013 varied by sampling date, but were similar to 2012 in that they peaked in mid-August and then fell in late August (Figure 3.9). The difference between 2012 and 2013 is that 2013 beetle captures were measured into September and there was a clear increase in captures on that sampling date. See Appendix 5 for a complete list of species and abundance.

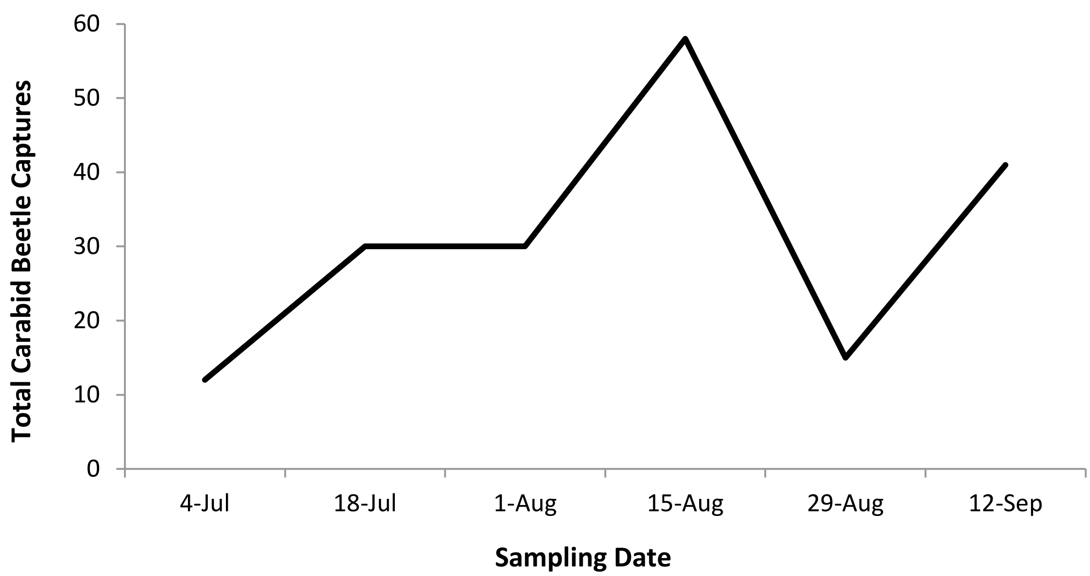

Figure 3.9. Total number of Carabidae captured in pitfall traps (n = 72 traps over 3 fields) placed in soybean fields, Nova Scotia, 2013.

There were no significant effects of distance in 2013 on carabid beetle captures (Table 3.11) but on four sampling dates there were significantly more carabids captured in soybean areas adjacent to legume + orchard grass perimeter treatments than in areas with a soybean perimeter (Figure 3.10). On July 18 there was a marginally significant effect of treatment on carabid beetle capture with three-fold more beetles/trap associated with legume + grass treatments than soybean field edges. On August 15, August 29, and

September 12, significantly more beetles were captured around legume + orchard grass than soybean perimeter treatments.

The second most common species captured in 2013, *A. sanctaecrucis*, is not an arthropod predator, but primarily a consumer of seeds (Menalled et al. 2001). Higher abundance associated with legume + orchard grass plots may have been due to habitat preference, as the soil seed bank should have been similar for both treatments since the legume and orchard grass plots were not producing or depositing seed over the 2013 growing season.

Carmona and Landis (1999) suggest that, in general, beetle abundance in agricultural systems may be higher in refuge areas (alternative crop areas) than in the crop fields themselves. There was no significant effect in my study of distance on the number of carabids captured in 2013, but the higher captures of carabid beetles associated with legume + orchard grass perimeter planting compared with soybean alone suggests that perimeter plantings can act as a wildlife corridor to move beneficial insects from the forest edge into the crop field (Joyce et al. 1999). Lys et al. (1994) had similar results, showing that weed strips within a cereal crop field can increase carabid beetle densities compared to control areas. House and All (1981) used mark and recapture techniques and found movement of carabids from fescue borders into soybean field.

Table 3.11. Effect of field border treatment and distance from field edge on carabid beetle capture in soybean fields, Nova Scotia, 2013 (Kruskal-Wallis tests).

Factor	***df***	Sample Date											
		Jul 5		Jul 18		Aug 1		Aug 15		Aug 29		Sep 12	
		X^2	P	X^2	P	X^2	P	X^2	P	X^2	P	X^2	P
Treatment	1	1.19	0.2757	2.78	**0.0953***	0.52	0.4700	3.92	**0.0476***	6.44	**0.0112**	14.05	**0.0002**
Distance	2	0.00	0.9980	2.20	0.3333	1.04	0.5935	4.19	0.1233	1.27	0.5313	0.89	0.6392

*P-values <0.1 bolded to show significance

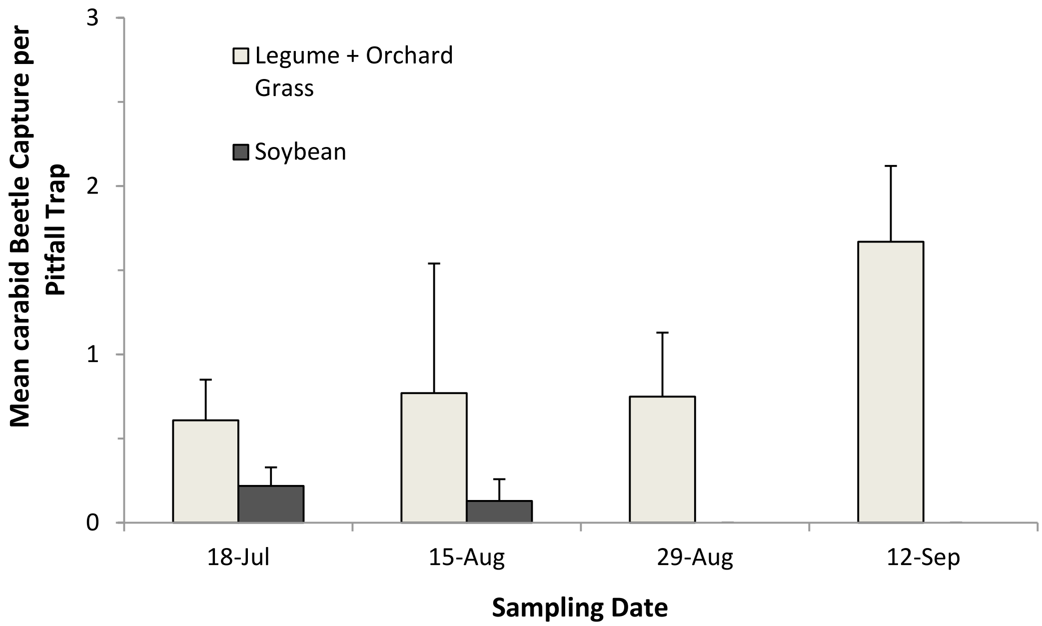

Figure 3.10. Mean (+/- SEM) Carabidae captured per trap in soybean fields (n=72, Nova Scotia, 2013) adjacent to two field-edge treatments. Effect of distance from field edge was not significant, so captures were combined across distances.

Perennial grasses such as *Dactylis sp.* (orchard grass), with unique tussocks that are important microhabitats and overwintering sites for carabid beetles and other potential beneficial insects (Luff 1966; Sotherton 1985; Thomas et al. 1991) could be especially useful. Although cash crops such as soybean and corn are generally only planted for one year as part of a crop rotation plan, perennial refuge areas may be established in order to provide stable habitat for populations of beneficial insects. MacLeod et al. (2004) found that beetle banks (a stand of perennial grasses) established within a cereal crop field contributed to conservation biodiversity in agroecosystems and provided an overwintering habitat for beneficial insects.

Soybean aphid was present only at the end of the season, and for a short period of time. There was no significant effect of treatment or distance on aphid abundance (Table

3.12), and there was no correlation of aphid abundance with beetle captures (Figure 3.11). Unlike the 2012 results, the scatterplot in Figure 3.11 suggests a relationship between the two variables, although many 0 counts for carabid beetles affected the correlation analysis.

Table 3.12. Effect of field border treatment and distance from field edge on presence of soybean aphid (*A. glycines*) Nova Scotia, 2013 (Mixed model ANOVA).

Factor	***df***	Sample Date			
		Aug 31		Sept 12	
		F	***P***	***F***	***P***
Treatment	1	0.07	0.7909	0.64	0.4379
Distance	2	0.50	0.6153	1.29	0.2898
Treatment x Distance	1	2.24	0.1443	0.47	0.4989

Firlej et al. (2013) found that *P. melanarius* readily preyed on soybean aphid but there was no significant reduction in soybean aphid populations over their two month study period. They observed high predation when soybean aphid densities were low, suggesting that carabid beetles are important for early season aphid control. Similarly, Landis and Van der Werf (1997) observed early season aphid predation by various coleopterans, including Coccinellidae and Carabidae, in sugar beet fields. A laboratory experiment carried out in Truro, NS at Dalhousie University Agricultural Campus in October, 2013 using two of the main species captured during this study found that *H.*

rufipes and *P. melanarius* will readily climb plant stalks in pursuit of aphids (Mullins 2013).

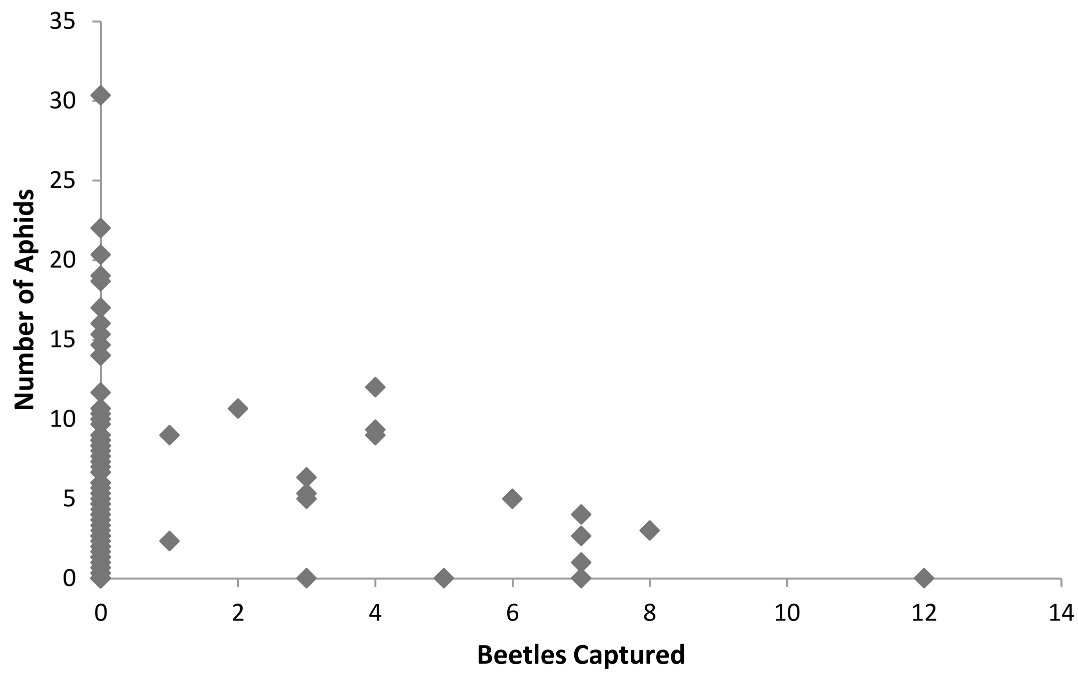

Figure 3.11. Soybean aphid abundance correlated against capture of Carabidae in soybean fields, Nova Scotia, 2013 (P = 0.6733; Correlation coefficient = 0.0944).

The duration of aphid presence in soybean fields in my experiments was short and occurred late in the season (late August-early September), which could explain why there was no relationship detected between carabid beetle captures and aphid presence. There was a sudden increase in carabid captures early in September, directly following a peak in aphid counts (Figure 3.12). It is possible that the increase in aphid populations in the soybean field attracted carabids. Winder (1990) found that peak aphid density was highest when the predator density was lowest and that ground dwelling predators (such as carabids) can reduce the rate at which aphids return to the plant canopy, where they tend to feed.

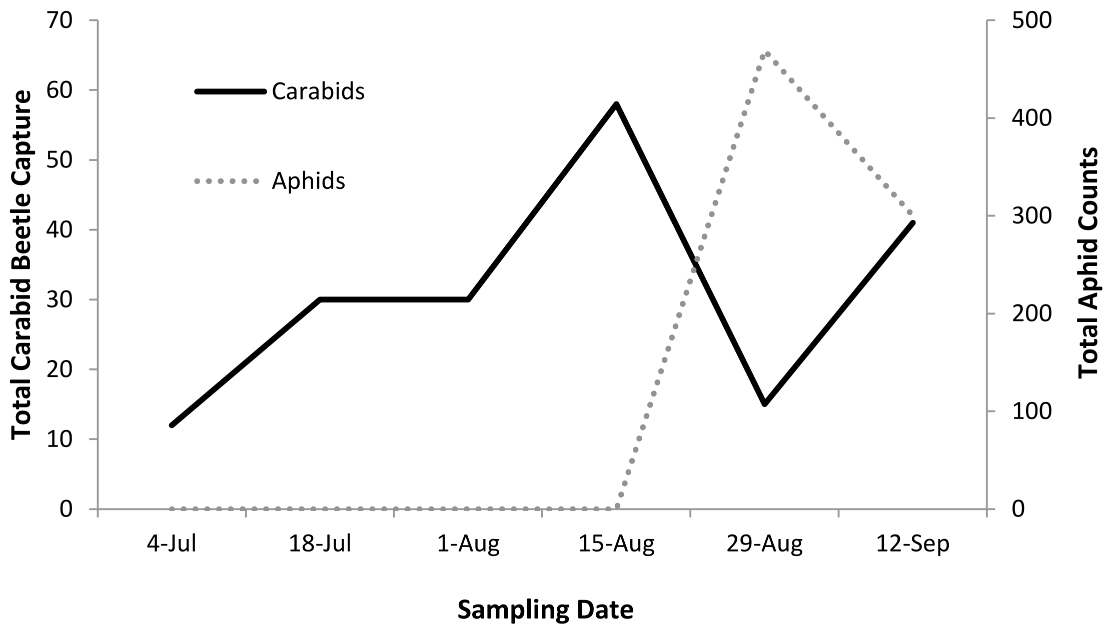

Figure 3.12. Carabidae captures in pitfall traps and aphid counts in soybean fields in Nova Scotia, 2013.

Although there is potential for carabid beetles to control aphids, the nutritional value of aphids for carabids may be low. A review by Toft (2005) highlighted benefits of specialist predators such as coccinellids that are fully capable of sustaining on an exclusively aphid-based diet as opposed to generalist predators such as carabids that require alternative prey sources to fulfill their dietary needs. This does not mean that carabids are not beneficial as predators of aphids, but it does highlight that Carabidae usually need alternative prey sources to subsist in a given habitat. Refuge areas or perimeter plantings of alternative vegetation can serve as a breeding ground/habitat for a variety of insects whereas a large monoculture crop field may only attract a small variety of insects and thus the beneficial generalist predators may be more likely to remain near the crop field to help control pest outbreaks.

CHAPTER 4 CONCLUSIONS

4.1 Overview of Objectives and Main Findings

This thesis research was aimed to implement integrated pest management (IPM) and holistic field management strategies in conventional soybean systems to mitigate white-tailed deer pest problems, while augmenting populations of beneficial carabid beetles. The overall objective of my research was to determine whether certain plants at field borders can concurrently encourage carabid populations while lowering entry of white-tailed deer into soybean fields and thus lower deer inflicted damage to soybean plants. It was predicted that an increase in carabid beetle populations would be associated with a decline in soybean aphid populations. Field research was carried out over the course of two growing seasons (June-September of 2012 and 2013) at seven different sites in Colchester County, Nova Scotia, Canada.

My main findings regarding white-tailed deer from 2012 did not show a reduction in deer-related soybean damage associated with any specific treatment. The overall soybean plant biomass at the end of the growing season was greater at 20 m into crop field than at field-edge. Generally, a higher abundance of carabid beetles close to field-edge as opposed to 20 m into soybean field was found in 2012. Soybean aphids were only present toward the end of growing season, and there was no correlation between aphid presence and carabid beetle abundance.

The plot sizes and number of treatments were modified from 2012 to 2013. Plot length was increased from 20 m to 80 m and the number of treatments was decreased from five to two. In 2013, deer presence was significantly higher at the forest/field edge than at 20 m into the crop fields. The greatest deer-inflicted soybean damage was seen at 1 m sampling areas adjacent to soybean perimeter planting; soybean plants adjacent to legume +grass perimeters saw significantly less grazing damage and had higher soybean pod biomass at the end of the season. There was evidence of deer feeding on legumes (alfalfa + red clover) which confirms the "trap crop" potential of the legume + grass perimeter planting. The carabid beetle captures for 2013 were 7 fold lower than captures for 2012. There were significantly more carabids captured in pitfall traps adjacent to legume + grass perimeter. Similar to 2012, there were low numbers of aphids, present only late in the season, and no correlation between aphid presence and carabid captures.

4.2 Limitations and Challenges

One major limitation to my research was the plot size for the 2012 field season. The plot size used for 2012 was 20 m x 4 m which was small, considering the large area that white tailed deer cover while foraging (based on visual observations). The length of the perimeter plots was increased to 80 m for 2013. Also, the number of treatments was decreased from five in 2012 to two in 2013 which allowed for more replications of treatments, leading to detection of significant differences between treatments. Another limitation to the research was the low incidence of soybean aphid in crop fields which made it difficult to perform statistical analyses.

Fall of 2012 brought minor flooding to the Colchester County area. Unfortunately this flooding happened while pitfall traps were open in the field. The lanes leading to soybean fields were inaccessible and therefore the beetle and aphid data for the last sampling date in 2012 could not be collected. Other challenges encountered during the field seasons included spray drift of glyphosate herbicide (soybeans were Roundup Ready ™) onto the perimeter plants, and locating the pitfall traps without disturbing the soybean plants.

4.3 Discussion of IPM Related to Thesis Research

There are three specific agricultural pest aspects of my thesis research: white-tailed deer, which is a vertebrate pest of soybean and many other crops; carabid beetles, which are generally acknowledged as beneficial insects in agroecosystems; and soybean aphid, an important pest of soybean. These three components are linked by the field-edge planting system I implemented. Although the concept of IPM is not new, the efforts to manage mammalian and insect pests using a single perimeter planting represents a novel approach to field management.

The literature review in Chapter 1 illustrates the importance of alternative vegetation to beneficial insects such as carabid beetles, and that many carabid beetle species (including prevalent species captured in my studies) are known predators of aphids (Thomas et al. 1992; Asteraki et al. 1995; Halaj et al. 2000; Landis et al. 2000; Menalled et al. 2001; Varchola and Dunn 2001; Fox et al. 2005; Hajek et al. 2007). The use of planted buffers at the forest edge before a crop field was suggested by others as a method to mitigate deer-grazing on cash crops (Lyon & Scanlon 1987; Hall and Stout 1999).

Although my research project focused on pest problems unique to soybean, the general concept of holistic field management demonstrated by the use of field-edge plantings can be applied to other agroecosystems where deer are a pest problem. This research is suitable for application to organic cropping systems as it does not require the use of chemical pesticides. The insect-related scope of this project could be narrowed to focus on one particular species of beneficial insect in a specific crop field (such as H. *rufipes* in soybeans) or it could be widened to focus on many beneficial arthropods, including parasitic wasps and spiders as well as other pest insects such as caterpillars.

4.4 Industry Application

The practicality for farmers of implementing field-edge plantings would depend on the specific crop type and its management. A drawback of implementing perimeter planting is the actual establishment and upkeep of the area. There is always the concern of weed populations encroaching on the crop area, and the potential of the alternative crops in the perimeter area to attract pest insects. If there is a high density of deer, the ability of the alternative crop to pull deer away from the cash crop may be compromised. This system would be better suited for moderate to low density of deer. If the cash crop is not attractive to deer (or if no deer are present to cause a problem) then the system could be altered to better suit beneficial arthropods by eliminating the legume portion of the mix and simply creating perennial grass stands however, the legume portion of the perimeter planting is important as legumes have the ability to fix nitrogen which supplies the grass portion with readily available nitrogen.

A further benefit to farmers who may implement a field-edge planting is the potential for the field-edge area to act as a buffer strip to filter runoff water containing chemical pesticides and fertilizer. Grasses are commonly used as buffer strips in riparian zones or at the edges of crop fields as they can grow extensive fibrous root systems to help filter ground water. If the field-edge planting contains legumes, there is the potential to harvest plants for animal feed, or as a green manure for the adjacent crop field. This could help to offset the initial cost of seeding/establishing the field perimeter.

Based on the findings from my study, a producer suffering from moderate to severe deer damage to soybean plants could expect an average yield of about 1.9 t ha^{-1} whereas a field with limited deer grazing damage could expect an average yield of about 2.6 t ha^{-1}. Using Burrow's 2013 field as an example, the yield expected from 8.4 ha is about 16 t with deer damage. If this same field had a field-edge planting and subsequently reduced grazing damage, the expected yield is about 20.5 (this takes into account the land lost to field-edge planting).

4.5 The Next Step

The next step, with regards to the soybean system, is to mark and monitor specific soybean plants for numbers of leaves and pods removed, and growth stage. Implementation of whole-field trials, as opposed to trial areas within fields, would be necessary to assess financial and physical feasibility of installing field-edge planting systems.

Monitoring of deer using motion sensing cameras and more frequent observation periods could provide better understanding of deer behaviour and food preference.

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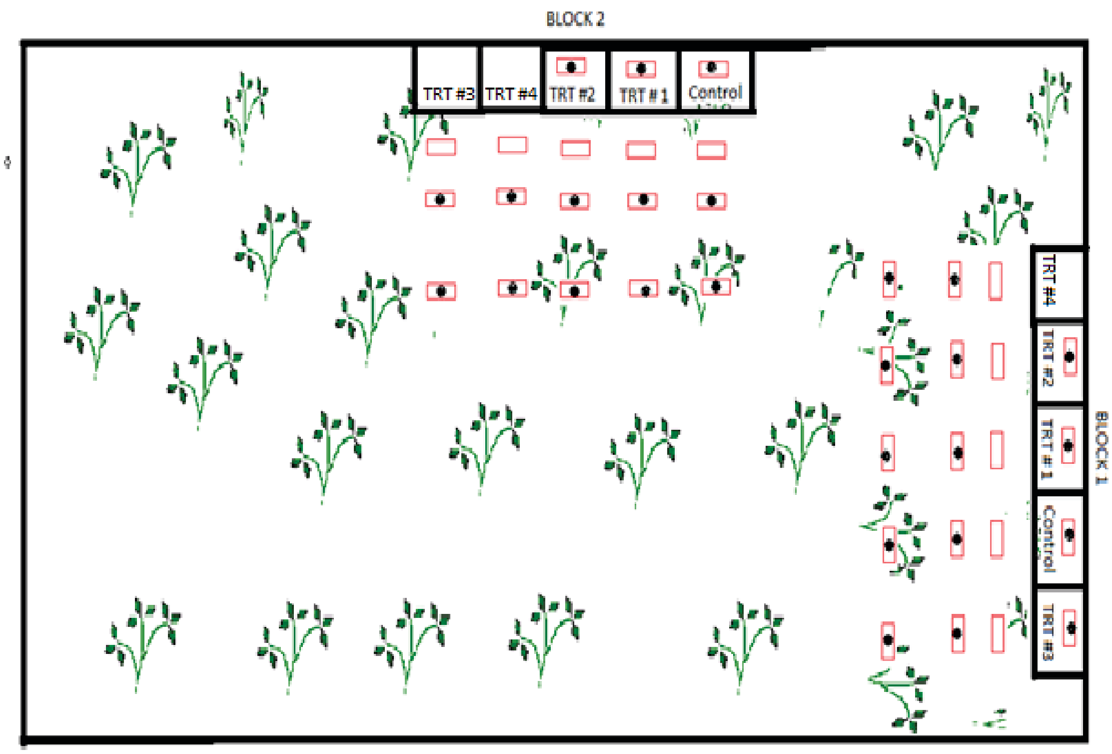
APPENDIX 1: Latin Names of Flowers

Common Name (Downeast mixture)	Latin Name
Blanket-flower	*Gaillardia sp.*
Yarrow	*Achillea millefolium*
Dwarf Coneflower	*Echinacea sp.*
Wallflower	*Erysimum sp.*
Lance-Leaved Coreopsis	*Coreopsis lanceolata*
Floxglove	*Digitalis sp.*
Purple Coneflower	*Echinacea angustifolia*
Baby’s Breath	*Gypsophila sp.*
Dense Blazing Star	*Liatris spicata*
Butter and Eggs	*Linaria vulgaris*
Scarlet Flax	*Linum grandiflorum*
Evening Primrose	*Oenothera sp.*

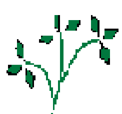
Common Name (Annual Surprise mixture)	Latin Name
African daisy	*Osteospernum sp.*
Baby Blue-Eyes	*Nemophila menziesii*
California Poppy	*Eschsholzia californica*
Creeping Daisy	*Widelia trilobata*
dwarf Godetia	*Clarkia amoena*
dwarf Plains Coreopsis	*Coreopsis tinctoria*
Five-Sport	*Leontopodium alpinium*
Rocket Larkspur	*Delphinium ajacis*
Spurred Snapdragon	*Linaria reticulate*
Sweet Alyssum	*Lobularia maritima*

APPENDIX 2: 2012 Field Maps

McCurdy's – Location: Onslow



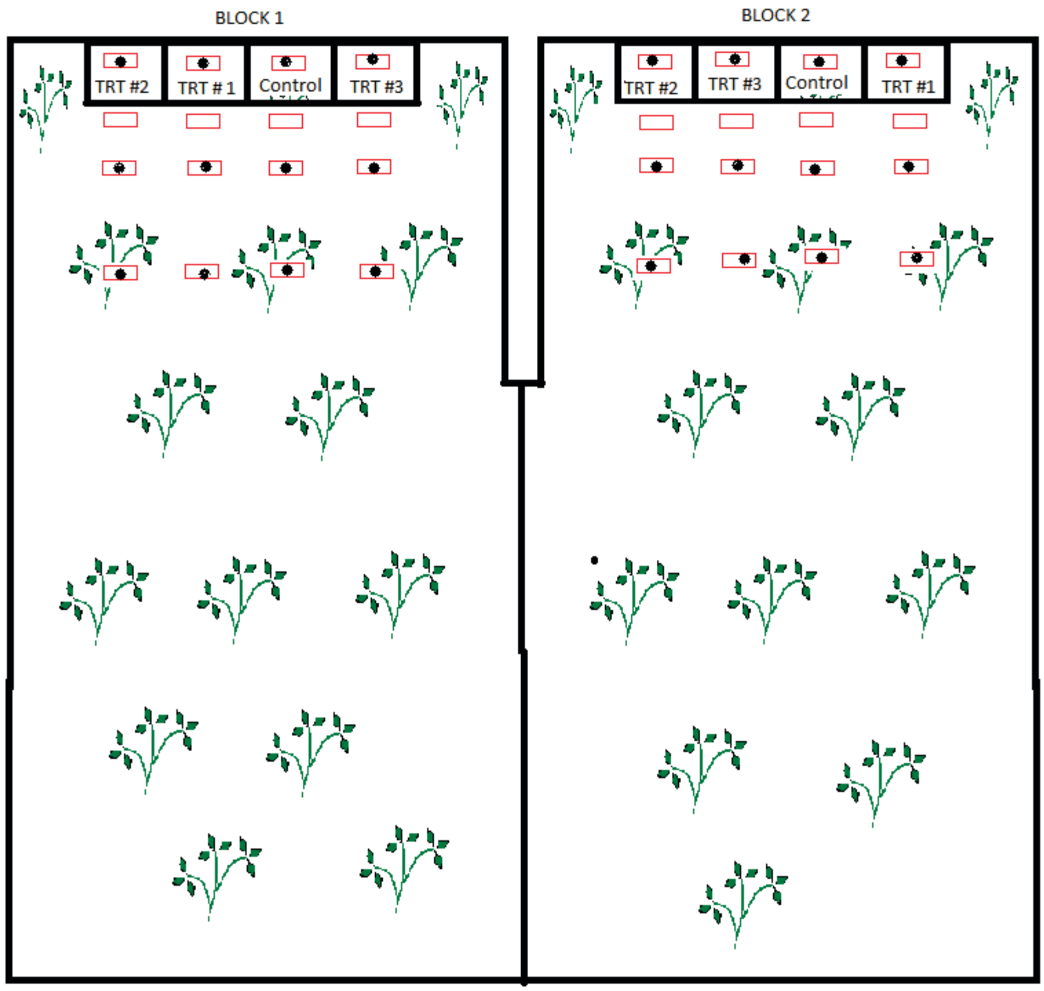
TRT #1 = Orchard Grass
TRT #2 = Orchard Grass + Legumes
TRT #3 = Mixed Herbs
TRT #4 = Wildflower Mix
CONT = Soybean

 = Soybean Plants

= 1mX10m section with pitfall trap

= 1mX10m section marked for sampling

Yuill’s – location: Beaver Brook



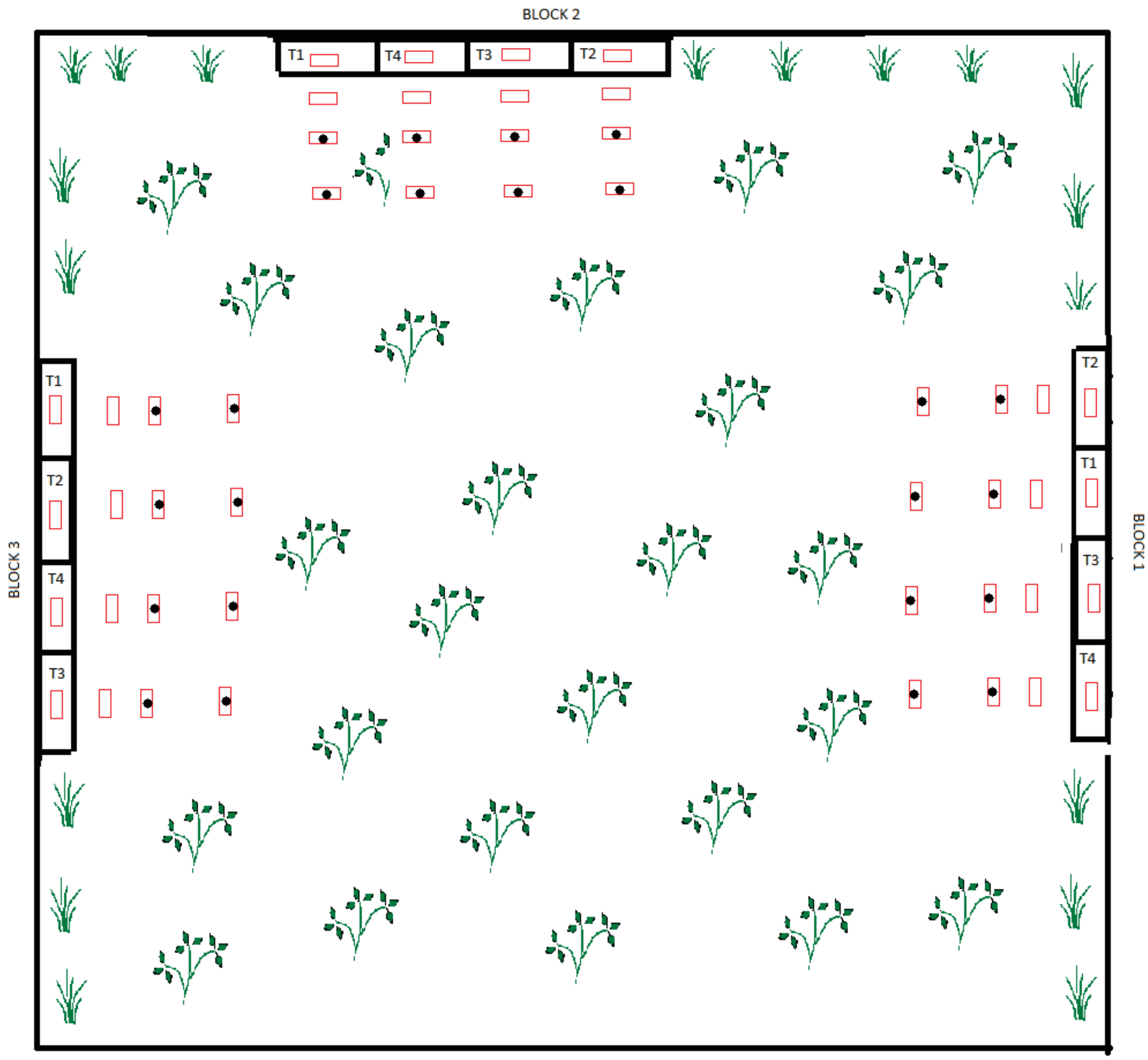
TRT #1 = Orchard Grass
TRT #2 = Orchard Grass + Legumes
TRT #3 = Mixed Herbs
CONT = Soybean

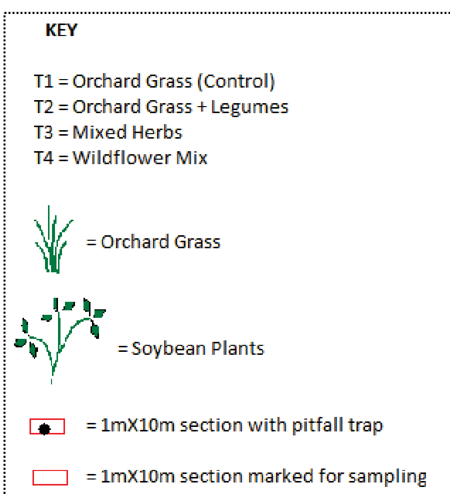
= Soybean Plants

= 1mX10m section with pitfall trap

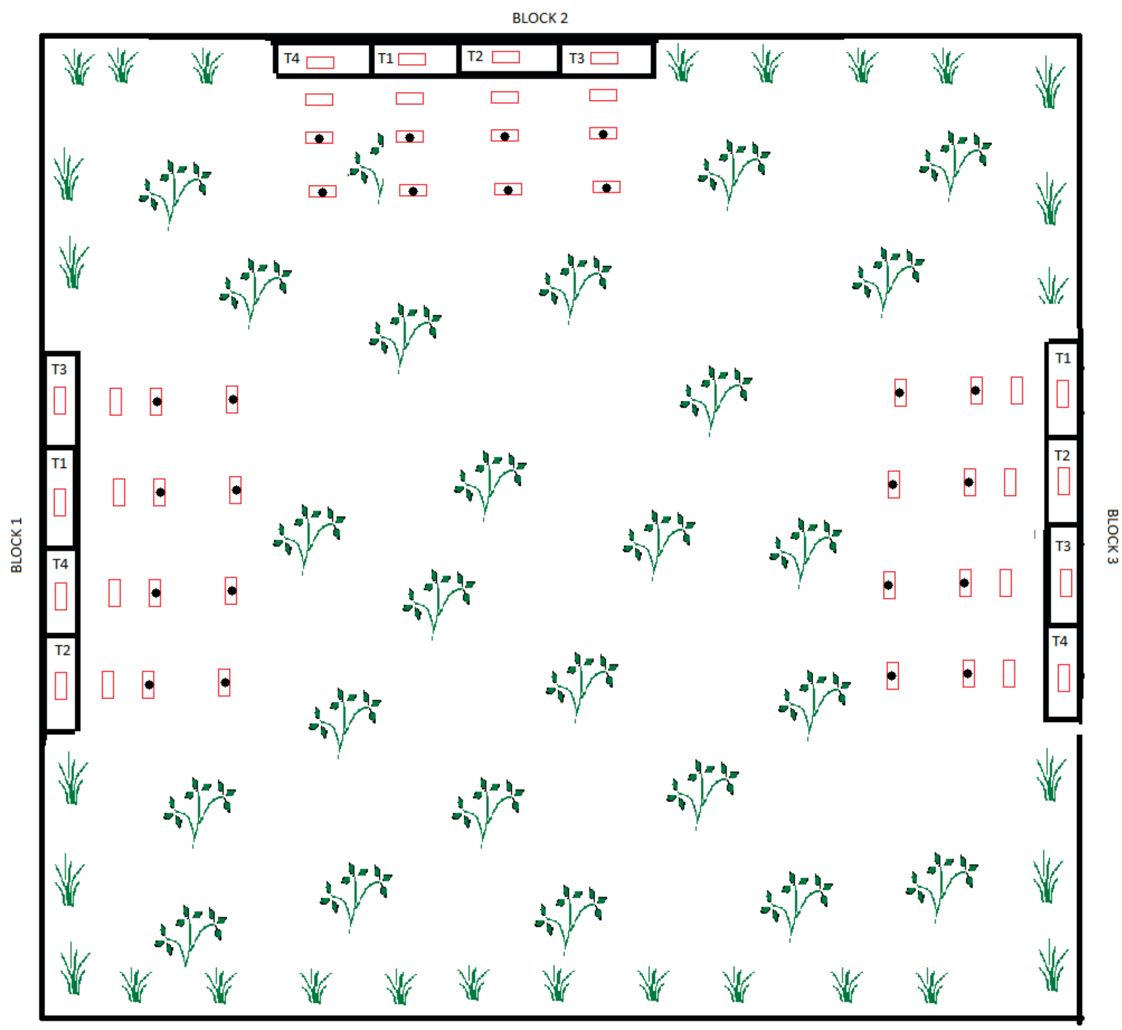
= 1mX10m section marked for sampling

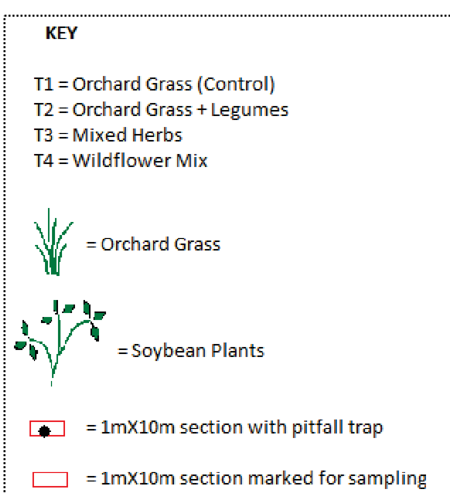
Burrows' – Location: Beaver Brook





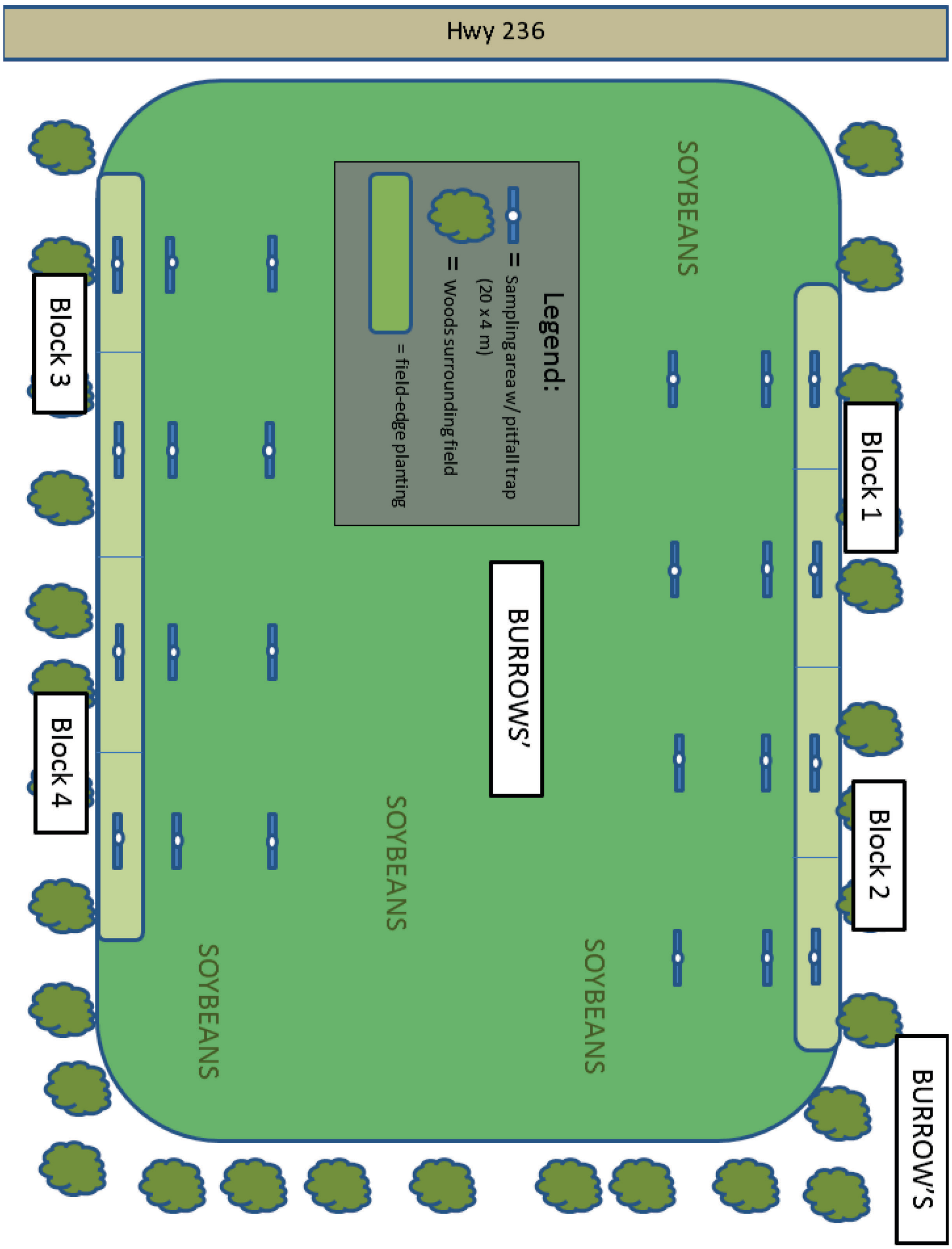
Baillie's – Location: Balfron





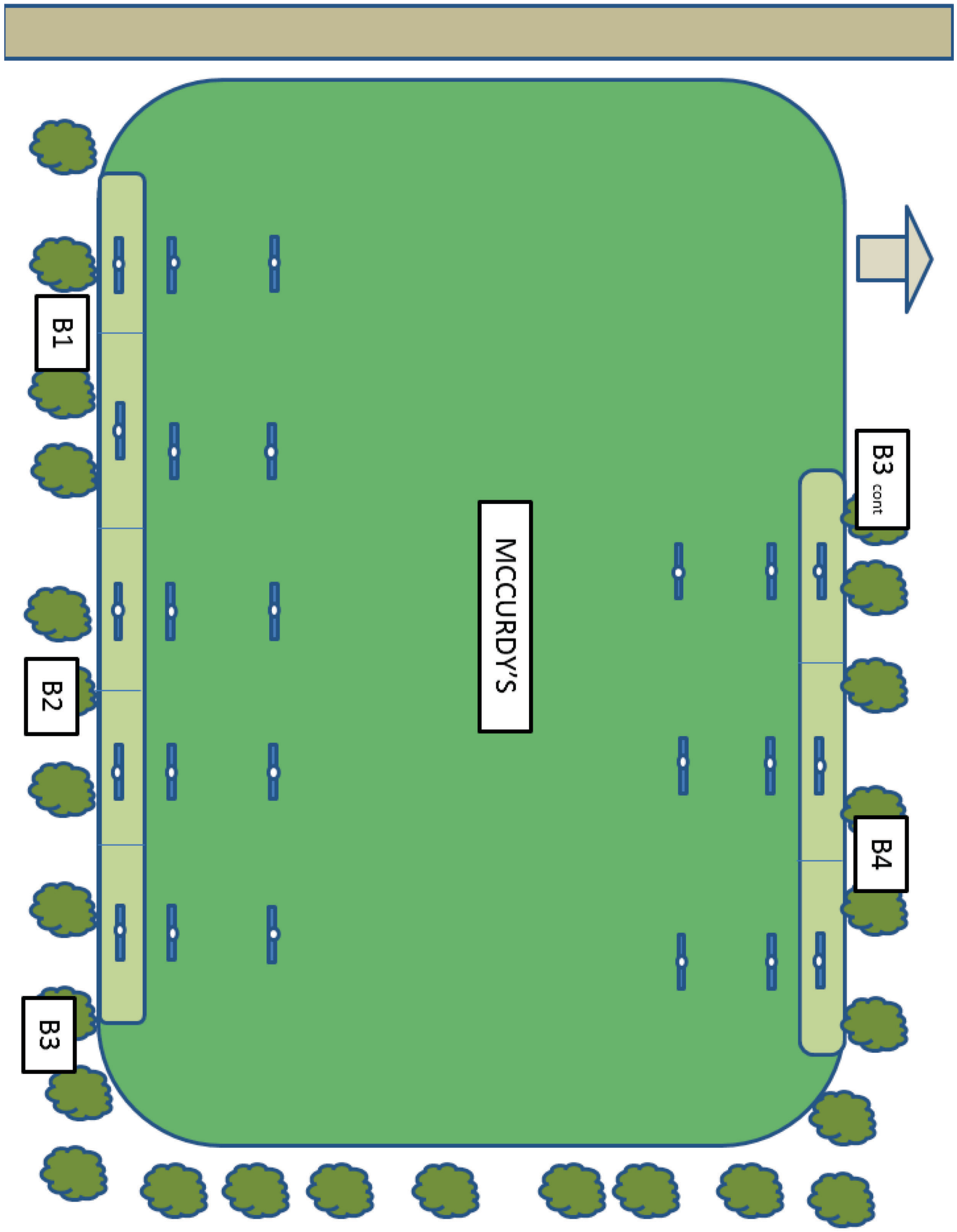
APPENDIX 3: 2013 Field Maps

Burrow's – Location: Beaver Brook



Yuill's (A and B) – Location: Beaver Brook

McCurdy's – Location: Onslow



APPENDIX 4: 2012 and 2013 Carabid Beetle Captures

Species and abundance, 2012

July 5, 2012

Genus	**Species**	**Author**	**Count**
Pterostichus	*melanarius*	Illiger	78
Harpalus	*rufipes*	DeGeer	31
Anisodactylus	*sanctaecrucis*	Fabricus	23
Agonum	*cupripenne*	Say	11
Agonum	*muelleri*	Herbst	9
Cicindelinae	*duodecimguttata*	Dejean	9
Chlaenius	*tricolour*	Dejean	8
Chlaenius	*sericeus*	Forster	1
Bembidion	*properans*	Stephens	4
Patrobus	*longicornis*	Say	3
Amara	*communis*	Panzer	2

July 20, 2012

Genus	**Species**	**Author**	**Count**
Pterostichus	*melanarius*	Illiger	126
Agonum	*muelleri*	Herbst	91
Harpalus	*rufipes*	DeGeer	70
Agonum	*cupripenne*	Say	35
Anisodactylus	*sanctaecrucis*	Fabricus	19
Chlaenius	*emerginatus*	Say	8
Chlaenius	*tricolour*	Dejean	4
Cicindelinae	*duodecimguttata*	Dejean	1
Harpalus	*somnulenus*	Dejean	1
Harpalus	*affinis*	Schrank	1
Stenolophus	*comma*	Fabricus	1
Notiophilus	*palustris*	Duftschmid	1

Aug 3, 2012

Genus	Species	Author	Count
Pterostichus	*melanarius*	Illiger	299
Harpalus	*rufipes*	DeGeer	118
Agonum	*cupripenne*	Say	42
Anisodactylus	*sanctaecrucis*	Fabricus	6
Agonum	*muelleri*	Herbst	4
Carabus	*nemoralis*	Muller	4
Chlaenius	*tricolour*	Dejean	4
Carabus	*granulatus*	Linnaeus	2

Aug 15, 2012

Genus	Species	Author	Count
Harpalus	*rufipes*	DeGeer	333
Pterostichus	*melanarius*	Illiger	209
Anisodactylus	*sanctaecrucis*	Fabricus	24
Agonum	*cupripenne*	Say	15
Agonum	*muelleri*	Herbst	2
Bembidion	*properans*	Stephens	1
Chlaenius	*tricolour*	Dejean	1

Aug 31, 2012

Genus	Species	Author	Count
Harpalus	*rufipes*	DeGeer	143
Pterostichus	*melanarius*	Illiger	84
Anisodactylus	*sanctaecrucis*	Fabricus	24
Anisodactylus	*nigrita*	Dejean	3
Harpalus	*somnulemus*	Dejean	3
Agonum	*muelleri*	Herbst	1
Patrobus	*longicornis*	Say	1

Species and abundance, 2013

July 4, 2013

Genus	Species	Author	Count
Pterostichus	*melanarius*	Illiger	6
Agonum	*muelleri*	Herbst	3
Anisodactylus	*sanctaecrucis*	Fabricus	2
Agonum	*gratiosum*	Mannerheim	1

July 18, 2013

Genus	Species	Author	Count
Pterostichus	*melanarius*	Illiger	13
Agonum	*muelleri*	Herbst	5
Harpalus	*rufipes*	DeGeer	5
Anisodactylus	*sanctaecrucis*	Fabricus	4
Chlaenius	*tricolor*	Dejean	2
Carabus	*granulatus*	Linnaeus	1

August 1, 2013

Genus	Species	Author	Count
Agonum	*cupripenne*	Say	14
Harpalus	*rufipes*	DeGeer	9
Pterostichus	*melanarius*	Illiger	4
Agonum	*muelleri*	Herbst	3

August 15, 2013

Genus	Species	Author	Count
Harpalus	*rufipes*	DeGeer	43
Anisodactylus	*sanctaecrucis*	Fabricus	17
Agonum	*muelleri*	Herbst	12
Agonum	*cupripenne*	Say	8
Pterostichus	*melanarius*	Illiger	3
Chlaenius	*tricolor*	Dejean	2

August 29, 2013

Genus	**Species**	**Author**	**Count**
Anisodactylus	*sanctaecrucis*	Fabricus	16
Harpalus	*rufipes*	DeGeer	8
Pterostichus	*melanarius*	Illiger	3

Sept 12, 2013

Genus	**Species**	**Author**	**Count**
Anisodactylus	*sanctaecrucis*	Fabricus	31
Harpalus	*rufipes*	DeGeer	16
Pterostichus	*melanarius*	Illiger	5
Agonum	*cupripenne*	Say	4
Agonum	*muelleri*	Herbst	4