PLANT BUGS (HEMIPTERA: MIRIDAE) ON BUCKWHEAT AND SEED ALFALFA CROPS IN MANITOBA: DYNAMICS, YIELD IMPLICATIONS AND MANAGEMENT

A Thesis

Submitted to

The Faculty of Graduate Studies

The University of Manitoba

by

Ayman Mahmoud Mostafa

In Partial Fulfillment of the Requirements for

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DOCTOR OF PHILOSOPHY

Department of Entomology

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AYMAN MAHMOUD MOSTAFA

A Thesis/Practicum submitted to the Faculty of Graduate Studies of The University of

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ABSTRACT

Ayman M. Mostafa. The University of Manitoba, 2007. Plant bugs (Hemiptera: Miridae) on buckwheat and seed alfalfa crops in Manitoba: dynamics, yield implications and management.

Supervisor: Dr. Neil J. Holliday

The assemblages of plant bugs in buckwheat and seed alfalfa in southern Manitoba mainly include the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois), and the alfalfa plant bug *Adelphocoris* spp. While the most abundant species of mirid plant bugs in buckwheat is *L. lineolaris*, this species and *Adelphocoris* spp. are about equally common in both organic and conventional fields of seed alfalfa. *Lygus lineolaris* has two generations in both crops in all the study locations. Lygus bug adults can move from drying swaths of canola near buckwheat and seed alfalfa late in the growing season. However, it seems that canola is not the only source of migrated lygus bugs late in the growing season. Low temperature and precipitation are likely to reduce the ability of migrating insects to move into the crops in late summer.

Caged buckwheat experiments showed that buckwheat yields were reduced mainly as a result of feeding of *L. lineolaris* nymphs at flowering stage. Insecticidal manipulation of insect populations confirmed this finding, and indicated that the nymphal population was synchronized with the flowering stage of the plant, mainly during August. In field insecticide trials, control that reduced nymphal populations at the flowering stage provided yields 12 – 78% greater than in unprotected controls. *Beauveria bassiana* applied against adults in September produced a significant fungal infection in bugs, although the number of bugs in treated and control plots did not

differ. The gain in yield as a result of this application was inconsistent. Similarly, conventional insecticide application in early September did not consistently provide significant yield benefits.

Over three years, controlling the plant bug population in seed alfalfa crops late in August and September did not result in greater yield quantity or quality than in untreated controls. This lack of yield response occurred despite the insecticide application effectively controlling the plant bug populations.

Dedication

To my mother and father, who gave me a love of life
To my wife, who gave me a life of love
To A'ser and Rohayma, who gave joy and meaning to it all
And
To the memory of my grandparents, whose wisdom lightens the pathway of my life

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CHAPTER I

General Introduction

Introduction

Buckwheat, *Fagopyrum esculentum* Moech., a food crop, and alfalfa, *Medicago sativa* Linnaeus, a forage crop, are well established crops in Manitoba. There are many differences between the two plants; alfalfa is primarily grown as a feed for livestock and is a perennial plant with seeds enclosed in pods (Goplen et al. 1987), whereas buckwheat is a human food and an annual plant with exposed flowers and seeds (Manitoba Buckwheat Growers Association 1998). Despite the differences between the two crops, alfalfa (Goplen et al. 1987; Soroka 1991; Harris 1992; Schaber 1992; Uddin 2005) and buckwheat (Elliott and Wise 2002; Wise et al. 2005) are commonly associated with the plant bugs in the family Miridae, order Hemiptera.

Plant bugs (Hemiptera: Miridae) have been reported attacking alfalfa crops throughout the world (Sedivy 1972; Sedivy and Kodys 1972; Holopainen and Varis 1991; Hori and Kishino 1992; Varis 1995), in North America (Shull et al. 1934; Hughes 1943; Jeppson and MacLeod 1946; Radcliffe and Barnes 1970; Gupta et al. 1980; Walstrom 1983), in Canada (Craig 1961; Craig 1963; Craig 1971; Schaber and Richards 1979; Smith and Ellis 1983; Murrell 1987; Harris 1992; Schaber 1992; Soroka and Murrell 1993; Summers 1998), and in Manitoba (Schaber 1992; Timlick et al. 1993; Uddin 2005). These plant bugs, mainly *Lygus* spp. and *Adelphocoris* spp., are pests of alfalfa grown for seed, and cause serious damage when they exceed their economic injury level or threshold. In Manitoba, the plant bug populations in seed alfalfa are usually controlled twice a season, firstly by the end of June when the plant is blooming, and secondly late in the growing season in late August.

Mirid plant bugs have recently been observed on buckwheat in Manitoba (Elliott and Wise 2002; Wise et al. 2005). *Lygus lineolaris* (Palisot de Beauvois) is the most abundant plant bug found in buckwheat fields in Manitoba, and there is evidence of nymphal stages developing in the crop. However, the first concern was a large population, mainly of adults, in August and September.

The sources of the late season population of plant bugs in buckwheat and seed alfalfa fields are not known, despite the suggestion they disperse from nearby senesced hosts. Concerns about the late growing season populations of plant bugs in buckwheat and seed alfalfa, along with uncertainity about the role of early growing season populations in buckwheat, and about the occurrence and structure of these populations provided the stimuli for initiating this research. The present study was designed to deal with these concerns and collect the required information to address the following objectives:

- To study the current seasonal occurrence of plant bug and species composition in seed alfalfa and buckwheat.
- To gather information about the quantities and sources of the lygus bugs moving into seed alfalfa and buckwheat field late in the growing season.
- To study the impacts of lygus bug populations on the yield of buckwheat.
- To study the impacts of plant bug populations late in the growing season on the yield of seed alfalfa.
- To find ways of managing plant bugs in seed alfalfa and buckwheat.

Thesis Organization

The thesis is divided into four main chapters: General Introduction, Literature Review, Research and General Discussion. The Literature Review is an introduction to information on the origins of alfalfa and buckwheat and their importance with particular reference to Manitoba, along with the distribution, importance, biology, sampling, movement and management of plant bugs. In the research chapter, I describe new research examining the species composition, late season population movements, impact and management of plant bugs, particularly *Lygus* species, in buckwheat and alfalfa crops in Manitoba. The chapter addresses the five objectives outlined above, and is divided into four parts, each in the style of a scientific paper. In General Discussion, I relate important findings and observations from the four parts of the Research chapter to provide general conclusions on the species composition, movements, impacts and management of plant bugs found in buckwheat and seed alfalfa crops in Manitoba.

CHAPTER II

Literature Review

Alfalfa crop, with particular reference to seed production in Manitoba

Alfalfa, *Medicago sativa* Linnaeus, is an important and popular forage crop worldwide. It probably originated in Asia more than 3300 years ago, and was first introduced to North America in Georgia in 1736, but did not become established as an important crop until 1850 in California (Goplen et al. 1987). A cold-hardy strain of alfalfa was introduced to the northern United States from Germany in 1857, and then to Canada, where several other strains were selected (Goplen et al. 1987).

Fresh or processed alfalfa is a nutritional feed for livestock, and humans consume alfalfa sprouts (Summers 1998). Alfalfa also enhances soil structure, improves water conditions, reduces salinity and fixes atmospheric nitrogen to increase soil fertility (Summers 1998).

Two production systems for alfalfa are found in the Canadian prairies, one for the production of animal feed and the other for seed production (Goplen et al. 1987). Alfalfa crops for feed production are usually mown one to three times in the growing season (Harper et al. 1990) to provide feed for livestock. The crop is either used directly by animals as hay or silage, or dehydrated for protein concentration and long-term storage (Goplen et al. 1987). Insect pests in hay fields are disturbed by mowing, which promotes for their dispersal and keeps them at low levels that usually do not cause economic damage (Schaber et al. 1990b). In the seed production system, leafcutting bees are used to increase pollination and yield of the seeds. The crop is swathed and at maturation, normally in September on the Canadian Prairies, the seeds are harvested by combine (Goplen et al. 1987). Alfalfa seed production value reached a record near $ 20 million Canadian in 2002, although it decreased by almost half in the following years (Manitoba Agriculture, Food and Rural Initiatives 2005c). The dominant insect pests of seed alfalfa in western Canada are two groups of plant bugs (Hemiptera: Miridae), the alfalfa plant bug, *Adelphocoris* spp. and plant bugs of the genus *Lygus* of which the most important is the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae) (Goplen et al. 1987; Soroka 1991; Harris 1992; Schaber 1992; Uddin 2005). Another important insect pest of seed alfalfa in Manitoba is the pea aphid, *Acrythosiphon pisum* Harris (Homoptera, Aphididae) (Uddin 2005). Insect pests have the potential to cause more economic damage to seed alfalfa than forage alfalfa because the crop is exposed to insect attack throughout most of the season. The main method for prevention of this damage in North America is use of insecticides. Typically, one or two applications of insecticide are made in Manitoba during the growing season of seed alfalfa (Uddin 2005), an early season application during late June and a late season application about the third week of August. In Manitoba, growers usually apply an insecticide just before introduction of leaf-cutting bees for pollination, as a clean-up treatment to control both aphids and plant bugs (Uddin 2005). When leaf-cutting bees are removed from the seed crop in August, producers often notice considerable numbers of plant bugs and apply a second spray.

Buckwheat crop origin and importance

Buckwheat, *Fagopyrum esculentum* Moech., has been cultivated in Manitoba since the early settlers from Ukraine brought its seeds to the Province. The cultivated area of buckwheat in Manitoba in 2005 was about 4,000 ha which produced 46,000 tonnes of seed (Manitoba Agriculture, Food and Rural Initiative 2005a). Manitoba buckwheat contributes about 70% of Canadian buckwheat production (Manitoba Buckwheat Growers' Association 1998); most of this production is exported to the south Asian market for the noodle manufacturing.

In Canada, no insecticides are registered for use on buckwheat, and until recently, insect pests were not considered a major impediment to buckwheat production. Recently in Manitoba, large numbers of adult lygus bugs have been observed on flower and seed heads of buckwheat near the end of the growing season, and earlier in the growing season immature lygus bugs are present in the crop (Wise et al. 2005). Before the completion of my research no information was available on the effects of lygus bugs on buckwheat yield and quality.

Plant bugs distribution and importance

Family Miridae, the plant bugs, is the largest family in order Hemiptera; with many important pests of economic crops worldwide (Wheeler 2001). Lygus bugs, *Lygus* spp., and alfalfa plant bugs, *Adelphocoris lineolatus* (Goeze), are the most widely distributed economic pests of this family.

Plant bugs of the genus *Lygus* are pests of many crops grown for seed (Strong et al. 1970). Pest species are found in North America, Europe, Asia, much of the Middle East and Africa (Gupta et al. 1980). In North America, 34 species are known, and 22 occur in the Prairie Provinces in Canada (Kelton 1980). At least nine species of the genus *Lygus* are of major importance to agriculture in North America, Europe and Asia (Kelton 1975). In North America, the more important species are *L. lineolaris*, *L. hesperus* (Knight), *L. elisus* (Van Duzee) (Gupta et al. 1980) and *L. borealis* (Kelton) (Kelton 1980). In the eastern and southeastern United States and in

Canada, the tarnished plant bug, *L. lineolaris*, can cause damage to more than 130 economically important crops, including 21 of the 30 most important crops in the United States (Young 1986). Affected crops include seed alfalfa (Shull et al. 1934; McMahan and Arrand 1955; Gupta et al. 1980), sunflowers, *Helianthus annuus* L., (Charlet 2003), apples, *Malus pumilla* P. Mill., (Hall 1974; Boivin and Stewart 1982; Weires et al. 1985; Michaud et al. 1989), bird's-foot trefoil, *Lotus corniculatus* L., (Neunzig and Gyrisco 1955; Wipfli et al. 1990), carrots, *Daucus carota* L., (Kho and Braak 1956; Scott 1983), cotton, *Gossypium* sp., (Pack and Tugwell 1976; Tugwell et al. 1976; Horn et al. 1999; Greene et al. 1999; Layton 2000), canola, *Brassica* sp., (Butts and Lamb 1990 a & b, 1991a & b; Turnock et al. 1995; Leferink and Gerber 1997; Wise and Lamb 1998a & b), wheat, *Triticum* spp., (Wise et al. 2000), green beans, *Phaseolus vulgaris* L., (Khattat and Stewart 1975; Stewart and Khattat 1980a & b), lima beans, *Phaseolus lunatus* L., (McEwen and Harvey 1960), asparagus, *Asparagus officinalis* L., (Wukasch and Sears 1981; Grafius and Morrow 1982), peaches, *Prunus persica* (L.) Batsch, (Rings 1958; Pree 1985), pears, *Pyrus* spp., (Webster and Spuler 1931), soybeans, *Glycine max* (L.) Merr., (Broersma and Luckmann 1970), strawberries, *Fragaria* spp., (Schaefers 1980; Mailloux and Bostanian 1988; Handley and Pollard 1993a & b), tomato, *Solanum lycopersicum* L., (Davis et al. 1963) and nursery stock (Haseman 1918). In the western parts of Canada and United States and southwestern United States *L. hesperus* and *L. elisus* are serious pests of seed alfalfa (Sorenson 1939), beans (Shull 1933; Middlekauff and Stevenson 1953; Elmore 1955; Scott 1969), cotton (Cassidy and Barber 1939), beets, *Beta vulgaris* L., (Hills and Taylor 1950; Carlson 1961), strawberries (Allen and

Geode 1963), carrots (Scott et al. 1966; Scott 1969, 1970) and other less important crops (Addicott and Romney 1950; Koehler 1963).

In the Canadian Prairies, lygus bugs are major pests of alfalfa (Craig 1983; Uddin 2005) and canola (Butts and Lamb 1991a). The most common species found on these crops are *L. elisus*, *L. borealis*, and *L. lineolaris* (Craig 1983; Butts and Lamb 1990a & b; Leferink 1992; Wise and Lamb 1998a & b; Otani 2000). The latter species is the most abundant in Manitoba (Timlick et al. 1993).

Alfalfa plant bug, *A. lineolatus*, is a serious pest of alfalfa grown for seed in North America (Hughes 1943; Craig 1961; Craig and Loan 1984a; Murrell 1987; Harris 1992; Soroka and Murrell 1993) and other parts of the world (Romankow 1959; Sedivy 1972; Hori and Kishino 1992). Alfalfa plant bug causes bud blast and flower drop which may eliminate the seed production in years with severe infestations (Sedivy and Kodys 1972). This insect also can cause damage to other forage crops like birdsfoot trefoil (Wipfli et al. 1990).

Biology of lygus bugs

Unlike most mirids which overwinter as eggs, plant bugs in the genus *Lygus* overwinter as adults and then emerge in the spring to feed on suitable host plants (Kelton 1975). Female inserts eggs in plant stems, causing minor injury (Painter 1929 and Wilson and Olson 1990). The preoviposition period of *L. lineolaris* ranges from 6.8 days at 32°C to 11.5 days at 21°C (Bariola 1969); for *L. hesperus* this period is 27 days at 12.8°C, 17 days at 15.6°C and 7 days at 26.7°C (Strong et al. 1970). Eggs develop and hatch in less than two weeks at 20°C, with no oviposition occurring among females held at 16°C (Ridgway and Gyrisco 1960a; Bariola 1969). No eggs develop at 10°C or 40°C, and some species like *L. lineolaris* have a shorter incubation period in the second generation than in the first one, possibly due to differences in physiological condition of the eggs and host plant and possibly humidity (Wheeler 2001). Generally, growth and development rates of different stages increase with increasing temperature (Khattat and Stewart 1977). Duration of nymphal instars 1-5 of *L. lineolaris* are 6-8, 3-6, 4-8, 5-7 and 7-10 days, respectively at 20°C (Ridgway and Gyrisco 1960a). The number of generations per year of lygus bugs depends mainly on the length of the growing season, the mean temperature (Leferink 1992) and the accumulated degree-days above 10°C (Champlain and Butler 1967), but other climatic conditions and host plants may also influence the number of generations (Kelton 1975). *Lygus lineolaris* has one generation in northern Alberta (Butts and Lamb 1991b) and northern Saskatchwan (Craig 1983), two generations in southern Saskatchewan, southern Manitoba (Timlick et al. 1993; Gerber and Wise 1995) and eastern Ontario (Painter 1929), three generations in southern Quebec (Stewart and Khoury 1976) and New York State (Ridgway and Gyrisco 1960b) and four or more generations in southern parts of the United States (Day 1987). Generally, lygus bugs are univoltine north of 53°30'N (Craig and Loan 1987) and bivoltine south of 50°N (Schwartz and Foottit 1992a). Winter survival of adults is positively correlated with moisture content of the overwintering sites (Fye 1982a). Photoperiods of 12.5 h of light or less induces diapause in lygus bug adults, and diapause terminates if adults are exposed to a 13.5 h or more of light per day (Bariola 1969).

Biology of *Adelphocoris lineolatus*

Alfalfa plant bug was first described as *Cimex lineolatus* by Goeze (Jensen 1986), before Reuter (1896) gave it its current name (cited in Hughes 1943). It was first recorded in North America in Nova Scotia in 1917, and was probably introduced as eggs in imported alfalfa seed (Knight 1930). The insect was first recorded in Manitoba in 1940 (Hughes 1943) and became abundant in the Interlake and southern regions by 1947 (Bird and Mitchener 1948). Within the subsequent two decades, alfalfa plant bug spread throughout the agricultural areas of Saskatchewan and Alberta, and now occurs on alfalfa throughout Canada. It is considered one of the most damaging insects to alfalfa (Goplen et al. 1987; Schaber 1992).

The alfalfa plant bug overwinters as eggs in the alfalfa plant stem, and hatches in spring (Craig 1963). The incubation period is 11 days at 28.6°C and 20 days at 18.6°C (Hughes 1943). The insect has five nymphal instars that develop respectively in 4-7, 1-8, 2-5, 2-4 and 4-6 days, respectively at a mean temperature of 26.3°C (Hughes 1943). Development time from egg to adult takes an average of 33.5 and 46 days at 25.7°C and 17.3°C, respectively (Hughes 1943).

This insect is largely univoltine north of 51°N, although two generations may occur if the winter is mild and spring is early in this area (Craig 1963). South of 51°N, alfalfa plant bug is mainly bivoltine (Craig and Loan 1984a).

Movement and occurrence of lygus bugs

In spring in the Canadian Prairies, overwintered lygus bug adults become active and colonize host plants, and then females mate and lay eggs inside the plant tissue (Craig 1973; Soroka 1991; Gerber and Wise 1995). The nymphs from these eggs first appear in May and numbers peak usually during the first half of June (Gerber and Wise 1995). These first generation nymphs reach adulthood usually during the second half of June and the peak adult abundance is during the first half of July (Craig 1973; Khattat and Stewart 1977; Soroka 1991; Gerber and Wise 1995). After about two weeks the first generation adults disappear. Second generation nymphs appear during late July and early August, peaking during mid August (Gerber and Wise 1995), followed by a peak of the second adult generation during mid to late August (Craig 1983; Murrell 1987; Gerber and Wise 1995; Braun et al. 2001). The second generation of lygus bugs in a crop generally appears to be more abundant than the first one, partly due to population build up (Craig 1983; Murrell 1987; Braun et al. 2001), but also because of migration from mature and senesced hosts late in the growing season (Murrell 1987).

Food quality, food quantity, and population density are the three ecological factors that most often affect insect movement in general and that of Heteroptera specifically (Rankin and Burchsted 1992; Otani 2000). Movement of *L. lineolaris* is affected by its age, sex and reproductive status (Stewart and Gaylor 1994). Young parous females are the colonizing stage of *L. lineolaris*, and have the longest flight duration (Stewart and Gaylor 1994). Lygus bugs commonly disperse from mature, dry or senesced hosts to more suitable hosts (Al-Munshi et al. 1982).

Disperseal of *L. lineolaris* from mature and senesced weed host plants, such as fleabane, *Erigeron* spp., to nearby cotton crops in the southern United States is a well known phenomenon resulting in damage to the cotton crop in this area (Cleveland 1982; Snodgrass et al. 1984a & b; Fleischer and Gaylor 1987). *Lygus lineolaris* can also move from alfalfa hay fields, after cutting, to nearby cotton resulting in damage to the cotton (Stern et al. 1964; Sevacherian and Stern 1974 & 1975). Weeds, seed alfalfa and hay alfalfa can play roles as sources of lygus bugs that infest nearby cotton fields, and distances between these source plants and cotton fields play a significant role in the dispersal of lygus bugs to nearby cotton (Carrière et al. 2006). If the infestation coincides with the early square (floral bud) stage of cotton it can cause shriveling of the buds, and bud drop from the plant (Tugwell et al. 1976); infestation of larger squares may interfere with fertilization (Pack and Tugwell 1976). Heavy infestation of small to medium cotton bolls may cause them to abscise or fail to open (Pack and Tugwell 1976). Infestation of larger bolls may result in damaged seeds (Pack and Tugwell 1976; Greene et al. 1999). Dispersal between alfalfa and soybeans can also cause damage to the soybeans crop (Poston and Pedigo 1975).

Dispersingal of lygus bugs from mature and senesced weeds and crop plants to canola in the Canadian Prairies can cause infestation of buds, flowers and pods, causing them to abscise, the seed to collapse, and a reduction in weight of healthy seeds per pod (Butts and Lamb 1990b, 1991a; Turnock et al. 1995).

Lygus bugs can move from senesced weeds and alfalfa crops to soybean crops (Freeman and Mueller 1989; Snodgrass et al. 1984b) causing economic damage to the bean crop. A similar situation is found with the movement of lygus bugs from these plants to celery (Stewart and Khoury 1976; Khattat and Stewart 1980), and beans and potato (Khattat and Stewart 1980).

Species composition and distribution of lygus bugs

There are approximately 43 known species of lygus bugs in the world, 34 of them occur in North America, seven in Europe and two in China (Kelton 1975). Most mirid species are restricted to the Nearctic region (Kelton 1980), with no European species in North America (Kelton 1975). The European tarnished plant bug, *L. rugulupennis* Poppius, is the most common lygus species in Europe (Varis 1995), with 437 host plants from 25 European countries and Iran (Holopainen and Varis 1991). This species is typically a pest insect in northern and central Europe, and causes only occasional economic damage in southern areas (Holopainen and Varis 1991).

In North America, *L. lineolaris*, *L. elisus*, *L. hesperus* and *L. borealis* are abundant in the agricultural area (Kelton 1975). *Lygus lineolaris* is the most widely distributed species of lygus bug in North America, occurring from central Alaska to Newfoundland to southern Mexico (Schwartz and Foottit 1992a), and is considered the principal mirid pest in the eastern and southern United States (Tingey and Pillemer 1977). *Lygus elisus* is reported in Alaska, northern and western Canada and western United States; *L. borealis* is found in Alaska, western Canada, and north central and north western United States, and *L. hesperus* is widely distributed in the western United States, north to British Columbia and likely south to Mexico (Kelton 1975, 1980).

The mirid plant bug assemblage and the species composition of lygus bugs in the Canadian Prairies exhibits variation among years, crops and sites (Schwartz and Foottit 1992a; Timlick et al. 1993; Gerber and Wise 1995; Braun et al. 2001;

Carcamo et al. 2002). *Lygus elisus* and *L. borealis* are the most abundant in Alberta and Saskatchewan and *L. lineolaris* is considered the most abundant in Manitoba (Schwartz and Foottit 1992a), but variation in relative abundance can occur within region (Craig 1983; Butts and Lamb 1990a; Timlick et al. 1993; Gerber and Wise 1995). In Saskatchewan, each of the three species dominates the lygus bug species assemblage in some portion of the growing season of alfalfa, while *L. lineolaris* is the dominant species in canola (Braun et al. 2001). In Alberta, the assemblage of lygus bug species in the northern boreal region is dominated by *L. lineolaris*, while the southern grassland region is dominated by *L. keltoni* (Carcamo et al. 2002). In the Interlake region in Manitoba, the percentages of *L. lineolaris*, *L. borealis* and *L. elisus* in alfalfa were 54, 36 and 10 %, respectively; and in the same crop in the Red River area they were 52, 30 and 18%, respectively (Timlick et al. 1993).

Sampling plant bugs

Precise and accurate information of insect population abundance is critical for effective decision making for any pest management program (Pedigo 2002). Accurate estimation of an insect population's abundance is rarely achieved because unbiased estimates are difficult to achieve in open field conditions (Southwood 1978). Precision and accuracy are usually balanced against sampling cost, which is the time and effort needed to carry out the sampling method.

Several sampling methods have been used to estimate the abundance of plant bugs of the family Miridae. Relative sampling methods, such as sweep netting, are commonly used with these pests (Schotzko and O'Keefe 1986; Uddin 2005). Many factors affect the accuracy of sweep net sampling: the time of the day, the person conducting the sampling, plant canopy density, insect distribution, species activity and density (Saugstad et al. 1967; Ellington et al. 1984; Schotzko and O'Keefe 1986; Uddin 2005). In some crops like cotton, a sweep net sampling is less accurate for sampling nymphs than the drop cloth method (Snodgrass 1993). Other sampling methods are available for plant bugs such as beat tray, fumigation tray, vacuum sampling and whole plant bag sampling. A vacuum sampling method was more precise in detecting nymphs than a visual inspection technique, although visual inspection can provide reliable estimates without the use of the special equipment that vacuum sampling requires (Knott et al. 2006). Sweep net sampling requires less time and effort, and can detect insects at low densities compared to other methods (Uddin 2005). Sweep net sampling provides more precise estimates over the growing season for lygus bugs in an alfalfa crop; however it is less efficient for providing absolute estimates and sampling nymphs (Uddin 2005).

Types of injury and damage of mirid plant bugs

Lygus spp. and *Adelphocoris* spp. cause similar types of effects on plants (Hughes 1943; Goplen et al. 1987; Hanna et al. 1987). Both nymphs and adults suck cell sap from plant tissues (Strong 1970; Craig 1973; Tingey and Pillemer 1977); they use piercing and sucking mouthparts, to penetrate host plant tissues (Tingey and Pillemer 1977). They feed by a lacerate and flush method without secretion of a stylet sheath; they secrete a small amount of saliva into the feeding site to liquefy the plant tissues before ingestion (Miles 1972).

Five categories of injury that can be caused by mirid plant bugs to crops are: 1) localized wilting and tissue necrosis, 2) morphological deformation of fruit and seed, 3) abscission of fruiting bodies, 4) altered vegetative growth, and 5) tissue malformation. Categories 2-4 are commonly found in alfalfa (Tingey and Pillemer 1977). The sucking of liquefied plant tissues, chemicals injected with saliva during feeding, and mechanical injuries due to feeding and oviposition cause wilting, discoloration and drying of tissues, a symptom called blasting (Smith and Michelbacher 1946; Leferink 1992). Mechanical injuries due to oviposition are usually minor, except when they become a pathway for entry of plant pathogens (Hughes 1943). While alteration of vegetative growth is a broad category, lygus bugs (Hughes 1943; O'Neal and Peterson 1971; Newton and Hill 1970) and alfalfa plant bugs (Hughes 1943) feeding on alfalfa's vegetative tissues may reduce plant height. When mirid plant bugs feed on plant leaves, the leaves become stunted or swollen and folded around the injured area, a phenomenon reported in plants such as cotton, sugar beet and poplar, but not alfalfa (Tingey and Pillemer 1977). With the progress of growth of the crop, mirid plant bugs feed on buds, causing bud blasting and on ovaries and other flower parts, causing flowers abscission (Hughes 1943; Tugwell et al. 1976; Tingey and Pillemer 1977; Goplen et al. 1987). Allowing one alfalfa plant bug to feed on five flowers for 24 h was sufficient to cause about 50% more flowers to collapse and drop than in uninfested controls; the damage was even greater when the insect fed on 10 flowers for 72 h (Hughes 1943). However, the same author observed a considerable number of flowers dropped even without any infestation, and concluded that flower mortality involves several factors including the injury of mirid plant bugs. With the appearance of seed pods and seeds, plant bug feeding causes distortion, shrinkage, and darkening of the young fruit or seed pods, resulting in reduced quality of seeds and dropping of young seed pods (Hughes 1943; Smith and Michelbacher 1946; Tingey and Pillemer 1977; Walstrom 1983; Soroka 1991).

The lygus plant bugs cause economic damage to more than 20 crops worldwide (Tingey and Pillemer 1977). *Lygus* spp. and *A. lineolatus* can cause significant economic damage to alfalfa crops, especially those for seed production, through reduction of seed quality and quantity (Hughes 1943; Craig 1963, 1971; Harper and Kaldy 1982; Craig and Loan 1984a; Murrell 1987; Soroka and Murrell 1993). The first record of alfalfa forage yield reduction due to lygus bug infestation was on second-crop alfalfa in Idaho (Shull et al. 1934), where *L. hesperus* and *L. elisus* feeding resulted in tip dieback, which may cause flower dropping and extensive branching of the plant (Jeppson and MacLeod 1946), and retard plant growth (Fye 1982b). Infestation by lygus bugs (Jensen 1986) and alfalfa plant bugs (Smith and Ellis 1983) affects the quality of alfalfa hay; in South Dakota, chemical control is recommended when there are 2.44 lygus bugs per sweep or 0.86 alfalfa plant bugs per sweep (Walstrom 1983).

Alfalfa seeds are directly damaged only by large nymphs and adults (Gupta et al. 1980). Feeding on flower buds, flowers, green pods and seed can increase numbers of damaged seeds and decrease numbers of racemes, pods, healthy seeds and seed germination (Hughes 1943; Sedivy 1972; Sedivy and Kodys 1972; Gupta et al. 1980). In Saskatchewan, an average of 22% of alfalfa seed damage was attributed to lygus bug infestation, with maximum losses reaching 51% in individual fields (Bolton and Peck 1946). Lygus bugs can reduce alfalfa seed production by 15 – 100% depending on their density (McMahon and Arrand 1955). Infestation of young seed pods by one alfalfa plant bug per five pods for 120 h resulted in 94.6% pod mortality (Hughes 1943). A significant yield reduction occurred when two or more alfalfa plant bugs were put in a sleeve cage with two alfalfa stems; however field trials in the same study showed no significant difference in yield between plots receiving an early season insecticide application and untreated check plots (Soroka and Murrell 1993). In a different study, seed yield from untreated alfalfa plots was 30% less than that from insecticide treated plots (Craig 1961). It is usual to consider the sum of the two types of mirid plant bugs, lygus bugs and alfalfa plant bugs, to determine a threshold for whether control is needed. Five bugs per 180° sweep of a sweep net at bud formation and the flowering stage is the threshold in Saskatchewan and Manitoba (Soroka 1991). Eight plant bugs or four nymphs at 4^{th} and 5^{th} instar and four adults per sweep justify early season insecticide applications in Alberta (Schaber et al. 1990a; Schaber 1992), and 12-16 plant bugs per sweep is a suggested late season threshold in Saskatchewan (Harris 1992).

In canola in Canada, lygus bug damage consists of lesions on the surface of stems, buds, flowers and pods, abscission of buds and flowers, seed collapse, reduced weight for healthy seeds and reduced yield (Lamb 1989; Butts and Lamb 1990b; Jones 2000). Caged canola plants showed indications of overcompensating for bud damage by lygus bugs (Butts and Lamb 1990b). However, lygus bugs can cause economically significant losses to canola in the field (Butts and Lamb 1991a); 52 lygus bugs per 10 sweeps at the early pod stage can reduce the yield by 11-35%. At the flowering stage, 15 lygus bugs per 10 sweeps is the economic threshold used for control at the end of flowering stage and the beginning of pod formation in Manitoba

(Wise and Lamb 1998b). This level depends on the plant moisture level and if the crop receives 10-15 mm of rainfall it can tolerate more damage.

An average of 15.5% reduction in yield occurs across a range of cotton cultivars when an initial population of 0.9 lygus bug nymphs per plant colonize cotton during the squaring stage (Meredith and Laster 1975). Lygus bugs can damage cotton bolls and influence the yield (Russell et al. 1999). Different economic thresholds have been developed for different cultivars of cotton in different stages for different parts of southern and western United States (Layton 2000).

Brown kernel spot is the symptom of lygus bug feeding on confectionary sunflowers, causing quality reduction in the seeds (Charlet 2003). In North Dakota, the economic threshold is one insect per 10 – 15 plants, each head of which contains 500 – 600 seeds (Charlet 2003).

The economic threshold of *L. lineolaris* on apple in Quebec ranges from 0.5 to 2.5 cumulative captures per sticky trap and 0.8 to 4.5 cumulative captures per limb trap, depending upon the cost of control and the development stage of fruit clusters during the period when insects were captured (Michaud et al. 1989).

The presence of one nymph per blossom cluster of strawberry resulted in a range of 29 - 45% injury and 9 - 20% yield reduction, respectively, in New York State (Schaefers 1980). Late season infestation of lygus bugs can cause strawberry fruit malformation (Easterbrook 2000). The economic injury level in strawberry fields in Quebec is estimated as 0.95 – 0.99 tarnished plant bug nymphs per blossom cluster, although the finding that 13% of the berries showed signs of injury at harvest led to an action threshold of 0.26 nymphs per blossom cluster (Mailloux and Bostanian 1988).

Fifth instar nymphs and adults of *L. lineolaris* damage the caged raceme of green beans at a density of one to two per cage, while the same density of the 3rd nymphal instar had no effect (Khattat and Stewart 1975). An economic injury level ranging between 0.3 and 4.4 insects per plant has been established for green bean, depending on crop use, control cost and plant stage infested (Stewart and Khattat 1980b). Caged green bean plants infested with *L. lineolaris* at bloom or pod set stage were more severely injured than those infested at the flower bud stage (Stewart and Khattat 1980a).

In wheat, lygus bug infestation can cause seed damage consisting of bleached areas of irregular shape that extend into the endosperm (Wise et al. 2000); these are associated with reduced seed weight and germination (Varis 1991).

Nymphs feeding on caged soybean buds and blossoms reduce the number of pods per node, the number of seeds per pod and the weight per seed, while adult feeding causes deleterious effects only on fruiting structures (Broersma and Luckmann 1970).

Lygus bugs are foliage pests of sugar beets (Bouchard et al. 1991, Hills and Taylor 1950), with capabilities to cause damage to sugar beet plant at different growth stages (Hills and Taylor 1950, Tamaki and Hagel 1978). Under certain conditions insecticide treatment late in the growing season can prevent yield loss in sugar beet crop in the Red River Valley (Boetel et al. 2004).

Damage to reproductive tissues is the typical injury from lygus bugs on asparagus (Wukasch and Sears 1981; Grafius and Morrow 1982), carrot (Scott 1983), sainfoin seeds (Morrill et al. 1998), peaches (Pree 1985), grain amaranth (Wilson and Olson 1992), bird's-foot trefoil seeds (Wipfli et al. 1990) and kenaf (Conti and Bin 2001).

Control methods of plant bugs

The struggle to control insect pests on crop plants is a continuous one. Several methods of control for plant bugs are available, but chemical control is still dominant.

Cultural control

Cultural control methods were dominant before the era of chemical control for insect pests. Burning, adjustment of harvesting methods and use of resistant varieties are the main methods of cultural control in North America (Blanchard 1933; Carlson 1940; Hughes 1943; Bolton and Peck 1946; Smith and Michelbacher 1946; Craig 1973; Soroka 1991; Summers 1998).

Burning the stubble and crop residues can be used as a method of insect pest control (Blanchard 1933). Spring burning of alfalfa stubble and residues can reduce the population of lygus bugs and alfalfa plant bugs (Hughes 1943; Bolton and Peck 1946; Craig 1973; Schaber and Entz 1988 & 1994). Some destructive effects on predator insects were recorded as a result of burning (Lilly and Hobbs 1962; Schaber and Entz 1988 & 1994). Applying fire late in the spring does not control pest insects and can delay seed set and maturity and increase the risk of frost damage (Bolton and Peck 1946). Several factors can influence the effectiveness of burning, such as insect species, age and growth of the plant, degree of damage, wind, weed control, dew, temperature and humidity (Schaber and Entz 1988, 1994).

Adjusting the harvest methods has been shown to control insect pests in Europe (Stary 1970) and North America (Blanchard 1933). Direct combining or immediate removal of the swath from the alfalfa field resulted in decreased insect pest populations and rapid recovery of the predator populations (Harper et al. 1990). Border- or strip-cutting leaves a narrow strip left uncut, which functions as refuge for predators and resulted in more predators than in solid-cut stands (van den Bosch and Stern 1969; Summers 1976). Border-cutting also lowered the number of lygus bugs (Godfrey and Leigh 1994). Technical and operational problems are the major obstacles that limit adoption of this method (Summers 1976; Harper et al. 1990).

A few cotton cultivars resistant to plant bugs, especially lygus bugs, are known, but the level of resistance is not sufficient to protect the crop effectively (Tingey and Pillemer 1977; Summers 1998).

Chemical control

Insecticides are the most frequent method used in controlling insects in North America (Broadbent et al. 2002). Inorganic insecticides were first used to control plant bugs before the development of synthetic insecticides. Many of these inorganic insecticides were reported to be ineffective against tarnished plant bugs (Painter 1929). Many factors can affect the efficacy of these chemicals such as sunlight, the physical and chemical nature of the compound, and moisture conditions in fields (Harper 1956). The era of synthetic insecticides started with DDT, and several organochlorine, organophosphate, carbamate and synthetic pyrethroid insecticides have been used against plant bugs. Many synthetic insecticides are recommended to control insect pests, including plant bugs, in alfalfa and other crops, including azinophos-methyl, cyhalothrin-lambda, dimethoate, malathion, naled and trichlorfon (Manitoba Crop Protection Guide 2006). With the many health, environmental and ecological concerns about synthetic insecticides, it is important to be cautious in their use. However, in a crop like alfalfa, seed growers usually apply insecticides twice a season regardless of the insect numbers and stages (Murrell 1987). In addition to environmental and health effects, frequent applications may cause the insect pest to develop resistance to insecticides, as has been reported for lygus bugs in the cotton belt in the southern United States (Snodgrass and Elzen 1995; Snodgrass 1996).

Biological control

There are large numbers of indigenous natural enemies of lygus bugs in North America in addition to exotic ones (Ruberson and Williams 2000). Some of these natural enemies can reduce lygus bug numbers in the field (Godfrey and Leigh 1994). Several species of coccinellids, chrysopids, nabids, anthocorids and carabids are active in alfalfa fields and can consume soft-bodied insects including aphid and plant bug nymphs (Wheeler 1974). Numerous investigations have been done on the effect of parasitoids on suppression of plant bugs, especially lygus bugs in North America. Ruberson and Williams (2000) and Broadbent et al. (2002) reviewed parasitoids of lygus bugs in North America, and listed the native and released exotic species, and described their effects. Little is know about egg parasitoids in North America (Broadbent et al. 2002). There are four active species of parasitoids which that attack lygus bug nymphs in Canada, including *Peristenus pallipes* (Curtis) (Broadbent et al.

2002), and some other species in the United States (Sorensen 1939; Clancy and Pierce 1966). Some European parasitoids, *P. adelphocoridis*, *P. conradi*, *P. digoneutis*, *P. rubricollis* and *P. stygicus*, have been introduced to North America (Carl 1979; Craig and Loan 1984a & b; Day et al. 1990). However, only *P. conradi* and *P. digoneutis* are established (Day et al. 1990, 1992).

Very few microbial agents have been tested for control of plant bugs. The ß–exotoxin of the bacteria *Bacillus thuringiensis*, known as Thuringiensin, caused higher mortality into 1st to 3rd nymphal instars than to 4th to 6th instars and adults (Tanigoshi et al. 1990). There are concerns, however, about the toxicity of this exotoxin to humans and animals (Weinzierl and Henn 1991). The entomopathogenic fungus *Beauveria bassiana* (Balsamo) can cause up to 90% mortality in many lygus bug species within a week of infection, and has the potential to recycle the infection within the population (Bidochka et al. 1993). *Beauveria bassiana* applications can reduce feeding of the tarnished plant bug, *L. lineolaris* (Soeglaff et al. 1997; Kouassi et al. 2003) and this is typical of fungal infection. However, in one study (Noma and Strickler 2000), *L. hesperus* infected with *B. bassiana* had elevated feeding rates.

Justification of the research project

Plant bugs, mainly *Lygus* spp. and *Adelphocoris* spp. (Hemiptera, Miridae), are known pests of many crops worldwide. For instance, the host plant range of *L. lineolaris* is considered one of the most diverse among all insects (Young 1986). Plant bugs mainly feed upon the reproductive tissue of plants, such as buds, flowers, pods fruits and seeds. As a result of the nature of damage, these insects can cause direct damage to many seed crops by their feeding. The dispersal ability of lygus bugs and large number of hosts including economic crops exacerbate concerns about these insects.

Seed alfalfa is an established forage crop in Manitoba, where it is attacked by many insects; the most important of them are *Lygus* spp. and *Adelphocoris* spp. These insects are controlled in June by insecticide application. While this early insecticide application is justified by an economic threshold (Manitoba Agriculture, Food and Rural Initiatives 2005b), a late growing season application in August, based on the threshold developed for the early season population, is probably not justified because plant growth stage and insect population structure differ from those of the early growing season.

Lygus bugs appear in buckwheat and seed alfalfa in large numbers, especially near the end of growing season. Given the known mobility of lygus bugs, most of the late season population is assumed to have dispersed from harvested or senesced hosts, particularly canola or forage alfalfa. The relationship between lygus bugs and buckwheat yield was not known at the time of initiating this research.

Distribution and number of generations of lygus bugs are determined by climatic factors and geographic location. Although the three species, *L. lineolaris*, *L. borealis* and *L. elisus* are the most dominant species in the Canadian Prairies, their distributions and voltinism vary.

Based on literature and the current status of plant bugs in seed alfalfa and buckwheat in southern Manitoba, several hypotheses were suggested, and then tested: firstly, that the late season populations of plant bugs in the seed alfalfa crop have economically important effects on the yield quality and quantity; secondly, that the lygus bug population in the buckwheat crop in southern Manitoba has economic impacts on yield quantity and quality; thirdly, that the source of late season population of lygus bugs in buckwheat and seed alfalfa is mainly from nearby harvested canola crops; and fourthly, that the number of generations and species assemblages of plant bugs in seed alfalfa and buckwheat are the same as in other crops in the Canadian Prairies.

CHAPTER III

RESEARCH

CHAPTER III – PART 1

The species composition and number of generations of plant bugs (Miridae: Hemiptera) in three Manitoba crops

Abstract

In a three year study, sweep net sampling at weekly intervals during the growing season was used to assess the composition of the mirid assemblage in canola, seed alfalfa and buckwheat in southern Manitoba. *Lygus lineolaris* was the most common species of lygus plant bugs in canola, buckwheat and seed alfalfa, consisting of and constituted over 90% of the *Lygus* spp. during the three year study In samples from both organic and conventional fields of seed alfalfa, *L. lineolaris* and *Adelphocoris* spp. were about 50/50% equally common. *Lygus elisus* and *L. borealis* together never exceeded 3% of the adult mirids in all samples from the three crops over the three years. From 2002 to 2004, *L. lineolaris* was bivoltine in alfalfa but produced one generation in canola and buckwheat.

Introduction

Approximately 43 species of lygus bugs are known worldwide; 34 occur in North America (Kelton 1975). Plant bugs in the genus *Lygus* (Miridae, Hemiptera) are important insect pests of seed alfalfa and many other crops in North America. *Lygus lineolaris* (Palisot de Beauvois), *L. borealis* (Kelton), *L. elisus* (Van Duzee) and *L. keltoni* (Knight) are the most abundant *Lygus* species in western Canada, and the first three species dominate in Saskatchewan and Manitoba (Craig 1963; Butts and Lamb 1990a & b; Gerber and Wise 1995; Uddin 2005). Alfalfa plant bug, *Adelphocoris lineolatus* (Goeze), is another mirid more specific to seed alfalfa. It was first recorded in North America in 1917 in Nova Scotia, and it was observed on alfalfa in Manitoba in 1941 (Hughes 1943). Along with pea aphid and lygus bugs, alfalfa plant bugs are considered the most destructive insect pests of alfalfa production in North America (Hughes 1943; Craig 1963; Radcliffe and Barnes 1970) and Manitoba (Uddin 2005).

When this research began, lygus bugs had often been observed on buckwheat in southern Manitoba. However, there was no information about the species composition and abundance of these bugs on buckwheat. Although the mirid plant bug species composition in seed alfalfa and canola are better known than in buckwheat, composition varies among years and sites (Schwartz and Foottit 1992a & b; Timlick et al. 1993; Gerber and Wise 1995; Braun et al. 2001; Carcamo et al. 2002). As the basis for subsequent examinations of the pest status and control of these insects, the species composition of lygus bugs currently infesting seed alfalfa and buckwheat in southern Manitoba are determined and compared among crops and locations. I hypothesized that the number of generations and species assemblages of plant bugs in seed alfalfa and buckwheat are the same as in other crops in the Canadian prairies.

Materials and Methods

Plant bugs in adjacent plots of alfalfa, canola and buckwheat at Carman, Manitoba

Three adjacent field plots of buckwheat (cv. "Koto"), canola and seed alfalfa (hereafter referred to as a triple plot) were established at the University of Manitoba Field Station at Carman (latitude 98° 2' 4" W and longitude 49° 29' 50" N) in 2002 and 2003. In each year, this triple plot did was not replicated, and the canola plot was located between the other two crops. Each plot measured 30 x 60 m in 2002 and 40 x 60 m in 2003. No insecticide was applied to the seed alfalfa and canola plots, but insecticide was applied to a portion of the buckwheat plot near the beginning of

August. All plots were planted and fertilized according to commercial practices. The seed alfalfa plot was supplied with leaf-cutting bees, *Megachile rotundata* F. (Hymenoptera: Megachilidae), to insure pollination.

Sweep net sampling of the field plots was conducted at weekly intervals throughout the two seasons. In 2002, eight sets of ten 180° arc sweeps with a 40 cm diameter muslin net were taken along the two diagonals of each seed alfalfa and buckwheat plot and five sets of 10 sweeps were taken from the canola plot. Sampling started on 6 June, 2 July and 22 July, and ended on 23, 9 and 23 September, 2002 for alfalfa, canola and buckwheat, respectively. An insecticide was applied to 2/3 of the buckwheat plot in late July, and so only four samples were taken in the unsprayed third of buckwheat after 5 August, 2002. In 2003, five sets of 10 sweeps were taken from each of the three crops using the same technique as in 2002. In 2003, the sampling started on 21 May, 2 and 16 July, and ended on 22 September, 25 August and 22 September in alfalfa, canola and buckwheat, respectively. After the insecticide application to half of the buckwheat plot, three sets of 10 sweeps were taken from the unsprayed portion; the reduced sampling began on 4 August 2003.

Samples were transported to the laboratory in an insulated cooler where they were frozen to kill and preserve the specimens. Plant bug adults were identified to species using the keys of Kelton (1975; 1980), Schwartz and Foottit (1992a), and Mueller et al. (2003). Although >95% of all alfalfa plant bugs were identified as *A. lineolatus* a few specimens were other *Adelphocoris* species, and so I will use the genus name for identifying all alfalfa plant bugs hereafter. Nymphs were identified to the genus level, and separated into two age groups: 1st to 3rd instar and 4th to 5th instar.

Plant bugs in conventional and organic fields of seed alfalfa

Each growing season from 2002 to 2004, mirid plant bugs were monitored in an organic seed alfalfa field to which no synthetic pesticides were applied and a conventional field that received dimethoate or cyhalothrin-lambda (Matador®) applications in late June and late August. Each year, different fields in the Interlake region of Manitoba were monitored. The conventional field in 2002 was located at 97° 16' 46" W 51° 1' 45" N, and the organic field was located at 97° 6' 1" W 50° 56' 56" N. In 2003, the conventional field was located at 97° 7' 11" W 50° 57' 2" N, and the organic field was located at 97° 11' 2" W 50° 56' 55" N. In 2004, the conventional field was located at 97° 22' 48" W 51° 2' 42" N, and the organic field was located at 97° 3' 0" W 50° 56' 56" N. In 2002, two 100 x 75 m sampling areas were established in each field. At weekly intervals, 10 sets of ten 180° arc sweeps were taken by sweep net along the two diagonals of each area with 25 m separating each set. By mid-August, the number of other insects, especially aphids, was so large that the number of sample sets was reduced to five. Sampling started on 12 June and ended on 19 September 2002. In 2003 and 2004, six sample sets were taken weekly by sweep net using the same technique as in 2002. Sampling started on 6 June 2003 and 9 June 2004 and ended 28 August 2003 and 31 August 2004. Samples were handled and insects were identified as described for plots at Carman.

Plant bugs in the commercial buckwheat field in 2003

To monitor plant bugs in buckwheat, sweep samples were collected from four replicates of the untreated check of the 2003 buckwheat commercial field trial near Altamont, Manitoba (98° 25' 15" W 49° 23' 19" N), one set of 10 sweeps was taken from each plot at weekly intervals (see Chapter III part 3 for sampling details). Sampling began on 16 July and ended on 22 September.

Statistics

Catches were standardized by calculating numbers of insects per 10 sweeps. Species composition of different *Lygus* species and *Adelphocoris* spp. was expressed as percentages of the total mirids captured.

Results

Plant bugs in adjacent plots of alfalfa, canola and buckwheat at Carman, Manitoba

In both 2002 and 2003, *Adelphocoris* spp. contributed a greater portion of the assemblage of mirids in the alfalfa field plot than in the buckwheat and canola plots, where *Lygus* species dominated (Table 1). About 90% of lygus bug adults in the alfalfa plot were *L. lineolaris. Lygus borealis* represented about 5% of the *Lygus* in the alfalfa plot in 2002 and 2003, and *L. elisus* represented almost 5% and 2% in 2002 and 2003, respectively (Table 1). *Lygus lineolaris* dominated in the buckwheat field plot in 2002 and 2003; in both years less than 1% of lygus adults in buckwheat were *L. borealis*, and *L. elisus* was seldom found (Table 1). About 97% and 99% of lygus bug adults were *L. lineolaris* in 2002 and 2003 respectively (Table 1). At least twice as many adult lygus bugs were found in buckwheat as in canola although the numbers of nymphs were similar in the two crops (Table 1).

Three peaks of *L. lineolaris* adults occurred in the seed alfalfa plot at Carman in 2002 and 2003 (Table 2). In 2002, the first peak was a small one in early to mid June, the second and largest peak was in July and a third peak occurred at the end of August. In 2003, the first peak was less and earlier, and the last peak was larger than in 2002 (Table 2). The numbers of alfalfa plant bug, *Adelphocoris* spp., showed two peaks in the same plots in 2002 and 2003, one during mid June to early July followed by a decrease in numbers during the rest of July and early August (Table 3). The second peak occurred during the second half of August, followed by a decrease in numbers toward the end of the season (Table 3). In canola there were two peaks of *L. lineolaris* adults, one in late July and the other in late August or early September (Table 2). The two peaks of adult *L. lineolaris* in the buckwheat plot occurred near the end of the third week of July and near the end of August or in early September in Carman; with a reduction because of low sampling efficiency during the first week of September due to rain in the area (Table 2).

Late in the growing season around the second half of August, lygus bug adult numbers doubled in seed alfalfa in 2003 and trebled in buckwheat in both years (Table 2). The number of lygus bug adults in the canola plot did not correspond to the late season peak in the adjacent seed alfalfa and buckwheat plots (Table 2).

Plant bugs in conventional and organic fields of seed alfalfa

In 2002, *Adelphocoris* spp. made up about 70% of the assemblage of mirid plant bugs in the organic field but only about half that in the conventional field (Table 4). The composition of lygus bug species in the organic and conventional fields in 2002 was dominated by *L. lineolaris*, then *L. borealis* and then *L. elisus* (Table 4). In 2003, *Adelphocoris* spp. dominated the mirid bug assemblage, and lygus bugs represented only 18% and 14% of mirids in conventional and organic fields, respectively (Table 4). *Lygus lineolaris* dominated the lygus bug species composition in conventional and organic fields with the remainder being *L. borealis* (Table 4). In

2004, *Adelphocoris* spp. dominance in the conventional field was greater than at any other time; in the organic field *Adelphocoris* spp. accounted for 70% of all mirid adults (Table 4). In the conventional field in 2004, *L. lineolaris* was the only *Lygus* species collected, but in the same year, while still dominant in the organic field, the percentage of *Lygus* that were *L. lineolaris* was the lowest recorded during the three years. Generally, catches of *L. lineolaris* adults in the organic and conventional seed alfalfa fields in the Interlake area were lower than those in the seed alfalfa field plots at Carman (Table 1 & 4). Peaks were not as distinctive as in the Carman plots due to the insecticide application in late June and third week of August in the conventional fields and the relatively low numbers present during 2002 – 2004 (Table 5). The number of *L. lineolaris* peaked during the mid to late August in both conventional and organic fields, and was probably augmented by an influx of adults during the first half of September in 2002 (Table 5).

In the commercial fields, the numbers of *Adelphocoris* spp. varied among years and field type (Table 6). There were distinct peaks around mid July in all the organic and conventional fields during the three year study, except the conventional field in 2004 when a peak occurred in early August (Table 6).

Plant bugs in the commercial buckwheat field in 2003

Lygus bugs dominated the mirid plant bugs in the commercial buckwheat field in 2003 (Table 7). All alfalfa plant bugs were adults. *Lygus lineolaris* dominated the lygus bug species composition; about 1% were *L. borealis* (Table 7). Two peaks of adult *L. lineolaris* occurred, the first during the third week of July and the second near end of August and the first week of September (Table 2). The reduction in numbers during the first week of September was because of low sampling efficiency due to rain.

Discussion

Adelphocoris spp. were more abundant than lygus bugs in alfalfa in all but one of the alfalfa systems sampled. The situation was different in buckwheat and canola where *Adelphocoris* spp. represented less than 5% of the mirid plant bugs. These results are in accord with previous observations that *Adelphocoris* spp. is more specific to alfalfa (Hughes 1943; Soroka 1991; Soroka and Murrell 1993). Furthermore, all of the alfalfa plant bugs in buckwheat were adults, suggesting that they may have occurred in buckwheat as transients, and did not develop in the crop.

The *Lygus* species found during this study were *L. lineolaris*, *L. borealis* and *L. elisus*, which is in accordance with the findings of Timlick et al. (1993) and Gerber and Wise (1995) in Manitoba. These results are similar to those of Craig (1983) in Saskatchewan and Butts and Lamb (1990 a & b) in Alberta. In this study *Lygus lineolaris* accounted for over 95% of lygus bug species in seed alfalfa crops compared to 52-54% in the same area in a study conducted about 10 years earlier (Timlick et al. 1993), indicating that *L. lineolaris* has become more dominant. A similar shift to greater dominance of *L. lineolaris* can be detected by comparing the current results with those of Timlick et al. (1993) in canola in the same regions. This situation for canola in southern Manitoba is in accord with the findings of Schwartz and Foottit (1992 b). *Lygus lineolaris* also comprised over 90% of lygus bug species in buckwheat, similar to the finding of Wise et al. (2005). This sampling confirms that *L. lineolaris* is the primary lygus bug species in alfalfa and canola and almost the only mirid pest of buckwheat in southern Manitoba.

There were three peaks in occurrence of adults of *L. lineolaris* in seed alfalfa near Carman and in the Interlake region. The first peak occurred in mid to late June, the second one in July and the third in late August. These peaks correspond to the overwintered, first generation and second generation of adults, respectively (Gerber and Wise 1995). *Lygus lineolaris* colonized canola and buckwheat at the time of flower initiation, which coincides with the occurrence of adults of the first generation that developed in seed alfalfa. These adults oviposit in canola and buckwheat, producing a generation that reached adulthood in late August, at about the same time as in seed alfalfa. However, the very high numbers of adult *L. lineolaris* that occurred late in the season, particularly in buckwheat suggest that adults that matured in the crop were probably augmented by adults that matured elsewhere.

Carman Station is located south of 50° N, and so is expected to have a bivoltine population of *L. lineolaris* (Schwartz and Foottit 1992a). The Interlake area is located north of 50° N, but still south of 53° 30' N, a transition area with some locations having univoltine populations of *L. lineolaris*, for example Vegreville (53° 29' N, 112° 3' W) (Butts and Lamb 1991b), but others such as Saskatoon (52° 8' N, 106° 38' W) having bivoltine populations (Craig 1983). Generally, the number of generations of lygus bugs per year is directly influenced by the accumulated degree-days above 10°C (Champlain and Butler 1967) along with other factors, like the including host plant availability (Kelton 1975). These factors appeared to favor development of two generations of *L. lineolaris* in the Interlake area, especially in 2002 and 2003.

This study shows that the number of generations and species composition of mirid plant bugs are similar in the Interlake and Carman areas in their number of generation and species composition. Although *A. lineolatus* is dominant in seed alfalfa, *L. lineolaris* predominates in both canola and buckwheat. The increasing dominance of *L. lineolaris* over the past decade; and its ability to produce two generations per year north of 50° N, gives this species an important role in the agricultural system of southern Manitoba. The large acreages of canola in Manitoba may enhance populations of *L. lineolaris* (Carcamo et al. 2002). Also favourable for this species are long season crops such as alfalfa (Hughes 1943) and late flowering crops like buckwheat and seed alfalfa (Hughes 1943; Soroka 1991). Thus, the sampled areas provide very favorable conditions, which can support completion of a bivoltine cycle, and probably increase overwintering success of *L. lineolaris*.

Table 1: Means of overall catches of alfalfa plant bugs and lygus bugs per 10 sweeps in adjacent field plots at Carman, MB in 2002 and 2003.

Year	Crop	Number of 10 sweep samples	Total mirid bugs	Total *Adelphocoris*	% *Adelphocoris*	Total lygus bugs	% of mirids that were lygus bugs			
							L. lineolaris	*L. borealis*	*L. elisus*	Nymphs
2002	Alfalfa	136	50.2	26.9	53.7	23.3	12.3	0.9	0.6	32.5
	Buckwheat	56	20.6	0.4	1.9	20.2	66.4	0.3	0.1	31.4
	Canola	50	16.7	0.6	3.6	16.1	41.6	1.3	0.2	53.3
2003	Alfalfa	95	35.8	22.1	61.6	13.7	19.5	1.4	0.5	17.0
	Buckwheat	39	21.4	0.4	1.7	21.0	74.4	0.2	0.0	24.8
	Canola	45	6.0	0.0	0.7	6.0	32.7	0.0	0.7	66.2

Table 2: Seasonal occurrence of *L. lineolaris* adults, as mean number (±SEM) of insects / 10 sweeps, in adjacent alfalfa, buckwheat and canola plots at Carman, MB in 2002 and 2003, and in buckwheat at Altamont, MB in 2003.

Date	Alfalfa	Buckwheat	Canola	Date	Alfalfa	Buckwheat	Canola	Buckwheat (Altamont)
3/6/02	0.9±0.2			21/5/03	0.2±0.2			
11/6/02	3.5±0.6			28/5/03	1.4±0.2			
17/6/02	4.0±0.6			4/6/03	0.4±0.2			
24/6/02	2.3±0.5			11/6/03	0.6±0.4			
2/7/02	4.1±1.2		0.6±0.2	18/6/03	2.6±0.7			
8/7/02	7.6±0.8		1.6±0.5	25/6/03	11.2±1.7			
15/7/02	24.4±3.4		6.6±0.7	2/7/03	18.2±4.7		1.8±0.6	
22/7/02	29.4±3.8	9.3±1.7	14.8±1.6	9/7/03	10.2±2.4		0.6±0.2	
29/7/02	16.5±2.4	8.8±2.8	19.6±4.7	16/7/03	2.2±0.7	2.2±0.6	5.4±2.7	0.5±0.3
5/8/02	9.3±1.7	4.3±0.9	8.4±1.8	23/7/03	9.2±0.9	7.6±2.2	3.8±1.2	2.5±1.0
12/8/02	2.5±0.6	3.3±0.7	2±0.3	28/7/03	5.8±1.2	3.8±1.2	0.2±0.2	6.5±1.8
18/8/02	2.4±0.6	0.8±0.5	10.2±1.9	4/8/03	7.8±1.4	8.0±1.7	0.8±0.5	6.8±1.7
26/8/02	4.1±1.2	7.3±1.5	4.6±1.7	11/8/03	8.2±1.0	3.7±1.7	0.6±0.4	4.0±1.2
2/9/02	1.5±0.6	28.8±5.1	3.6±0.7	18/8/03	16.6±3.9	18.3±3.6	1.8±0.7	9.5±4.5
9/9/02	1.5±0.5	56.5±8.9		25/8/03	18.8±3.3	66.7±16.9	3.0±0.9	40.0±5.4
16/9/02	1.4±0.5	47.8±10.4		1/9/03	10.4±1.5	15.7±4.1		20.0±2.5
23/9/02	2.9±1.1	7.8±2.9		8/9/03	15.6±1.8	42.3±11.4		45.8±4.0
				15/9/03	5.0±1.1	19.7±5.0		11.3±3.0
				22/9/03	1.2±0.4	9.0±2.2		4.0±0.8

Table 3: Seasonal occurrence of *Adelphocoris* spp. (Mean±SEM) in alfalfa at Carman, MB in 2002 and 2003.

Date	Number of insects/10 sweeps	Date	Number of insects/10 sweeps
3/6/02	0.0±0.0	21/5/03	0.0±0.0
11/6/02	0.3±0.2	28/5/03	0.0±0.0
17/6/02	0.3±0.3	4/6/03	0.0±0.0
24/6/02	2.0±0.5	11/6/03	0.0±0.0
2/7/02	47.9±3.8	18/6/03	8.2±1.2
8/7/02	36.8±4.0	25/6/03	15.6±2.8
15/7/02	20.0±5.4	2/7/03	12.8±3.2
22/7/02	6.9±1.7	9/7/03	1.8±0.7
29/7/02	8.4±1.2	16/7/03	2.4±0.9
5/8/02	5.1±1.0	23/7/03	2.4±0.7
12/8/02	13.0±2.0	28/7/03	2.2±0.4
18/8/02	13.8±1.1	4/8/03	2.6±0.2
26/8/02	26.1±3.4	11/8/03	22.8±2.8
2/9/02	14.6±1.8	18/8/03	20.6±4.6
9/9/02	9.6±1.5	25/8/03	21.8±5.7
16/9/02	5.6±1.3	1/9/03	19.2±7.9
23/9/02	0.5±1.9	8/9/03	10.6±3.5
		15/9/03	4.8±1.7
		22/9/03	2.2±0.8

Table 4: Means of overall catches of alfalfa plant bugs and lygus bugs per 10 sweeps in organic and conventional fields of alfalfa in the Interlake region, MB in 2002 – 2004.

Year	Crop	Number of 10 sweep samples	Total mirid bugs	Total alfalfa plant bug	% alfalfa plant bug	Total lygus bugs	% of mirids that were lygus bugs			
							L. lineolaris	*L. borealis*	*L. elisus*	Nymphs
2002	Organic	206	33.1	23.2	70.2	9.9	3.0	0.5	0.2	26.1
	Conventional	206	5.7	2.0	34.6	3.7	20.0	2.0	0.8	42.6
2003	Organic	78	25.6	22.2	86.8	3.4	4.0	0.2	0.0	9.0
	Conventional	78	15.0	12.3	82.3	2.7	11.2	0.1	0.0	6.4
2004	Organic	78	25.0	17.4	69.5	7.6	2.4	0.4	0.5	27.3
	Conventional	78	36.1	34.8	96.3	1.3	0.3	0.0	0.0	3.4

Table 5: Seasonal occurrence of *L. lineolaris*, as mean number (±SEM) of insects / 10 sweeps, in organic and conventional alfalfa fields in the Interlake area, MB.

2002			2003			2004		
Date	Organic	Conven -tional	Date	Organic	Conven -tional	Date	Organic	Conven -tional
12/6	1.0±0.3	0.8±0.2	5/6	0.0±0.0	0.3±0.2	9/6	0.2±0.2	0.2±0.2
19/6	1.0±0.3	0.9±0.3	12/6	0.3±0.2	0.0±0.0	16/6	0.2±0.2	0.0±0.0
26/6	0.8±0.2	0.1±0.1	19/6	1.0±0.6	0.5±0.2	23/6	0.2±0.2	0.0±0.0
5/7	0.2±0.1	0.2±0.1	26/6	0.2±0.2	0.3±0.3	30/6	0.3±0.3	0.0±0.0
12/7	1.7±0.4	0.5±0.1	3/7	1.8±0.4	1.2±0.2	6/7	0.3±0.2	0.0±0.0
19/7	2.5±0.5	0.4±0.2	10/7	2.2±0.8	1.3±0.6	13/7	0.0±0.0	0.0±0.0
26/7	0.7±0.2	1.2±0.4	17/7	0.8±0.3	0.3±0.3	20/7	0.0±0.0	0.0±0.0
1/8	0.0±0.0	0.4±0.2	24/7	0.7±0.7	0.8±0.4	27/7	0.0±0.0	0.0±0.0
8/8	1.5±0.5	0.8±0.3	31/7	1.0±0.3	0.2±0.2	3/8	1.5±0.9	0.0±0.0
15/8	2.0±0.3	1.8±0.4	7/8	2.7±0.2	0.8±0.5	10/8	0.0±0.0	0.2±0.2
21/8	1.2±0.3	2.8±0.6	14/8	1.2±0.5	5.0±1.2	17/8	1.8±1.1	0.2±0.2
30/8	1.8±0.5	2.5±0.3	21/8	1.0±0.4	8.2±1.8	24/8	1.7±0.5	0.2±0.2
5/9	0.5±0.2	1.8±0.2	28/8	0.5±0.3	2.8±0.7	31/8	1.5±0.6	0.8±0.3
12/9	0.0±0.0	6.2±1.1						
19/9	0.7±0.5	8.7±2.5						

Table 6: Seasonal occurrence of *Adelphocoris* spp., as mean number (±SEM) of insects / 10 sweeps, in organic and conventional alfalfa fields in the Interlake area, MB.

2002			2003			2004		
Date	Organic	Conven-tional	Date	Organic	Conven-tional	Date	Organic	Conven-tional
12/6	0.0±0.0	0.0±0.0	5/6	0.0±0.0	0.0±0.0	9/6	0.0±0.0	0.0±0.0
19/6	0.0±0.0	0.0±0.0	12/6	0.2±0.2	0.0±0.0	16/6	0.0±0.0	0.0±0.0
26/6	0.2±0.1	0.0±0.0	19/6	3.2±0.4	0.0±0.0	23/6	0.0±0.0	0.0±0.0
5/7	13.0±1.4	0.7±0.2	26/6	3.8±1.7	1.0±0.3	30/6	0.0±0.0	0.0±0.0
12/7	44.1±5.5	1.5±0.3	3/7	8.2±2.2	2.0±1.0	6/7	0.0±0.0	0.0±0.0
19/7	21.4±3.6	2.0±0.4	10/7	21.2±3.0	2.5±0.6	13/7	3.0±1.3	0.3±0.3
26/7	17.9±3.5	1.2±0.3	17/7	9.3±3.0	4.3±1.4	20/7	15.0±2.5	3.7±1.1
1/8	3.9±1.3	1.1±0.2	24/7	8.3±2.8	20.7±2.2	27/7	6.7±1.8	6.5±1.9
8/8	8.3±1.6	2.1±0.7	31/7	9.2±2.1	11.7±2.7	3/8	5.3±0.8	10.8±4.5
15/8	12.7±2.0	3.2±0.6	7/8	5.5±2.7	9.5±2.8	10/8	2.7±0.8	10.0±2.8
21/8	13.1±1.9	5.2±0.7	14/8	6.3±0.4	5.0±1.2	17/8	1.3±0.6	14.3±4.2
30/8	28.2±4.3	7.0±0.3	21/8	4.8±1.0	6.7±1.9	24/8	1.0±0.6	14.2±4.3
5/9	1.8±0.3	0.8±0.3	28/8	1.0±0.4	1.5±0.7	31/8	0.5±0.2	18.0±4.9
12/9	4.7±1.9	3.0±1.1						
19/9	3.5±1.2	1.3±0.4						

Table 7: Means of overall catches of alfalfa plant bugs and lygus bugs per 10 sweeps in commercial buckwheat at Altamont, MB in 2003.

Number of 10 sweep samples	Total mirid bugs	Total alfalfa plant bug	% alfalfa plant bug	Total lygus bugs	% of mirids that were lygus bugs			
					L. lineolaris	*L. borealis*	*L. elisus*	Nymphs
206	16.4	0.4	2.3	16.0	83.0	0.6	0.0	14.1

CHAPTER III – PART 2

Movement of lygus bugs into seed alfalfa and buckwheat crops late in the growing season in southern Manitoba

Abstract

Sweep net and suction trap sampling were used to study the movement of lygus bugs late in the growing season. In a system of adjacent plots of canola, buckwheat and seed alfalfa, lygus bugs moved from drying swaths of canola to the other two plots, particularly to buckwheat. Comparisons of the numbers of insects in canola plots to those in the adjacent seed alfalfa and buckwheat plots suggested that the canola plot was not the only source of dispersing lygus bugs late in the growing season. Low temperature and high precipitation likely reduced the movement of these dispersing insects. The movement of lygus bugs into commercial fields of seed alfalfa and buckwheat was more evident when there was a nearby canola field.

Introduction

Lygus bugs generally overwinter as adults (Kelton 1975). With the increase in temperature in spring they emerge and females oviposit on the hosts that are available then. The number of reproductive generations that follow depends upon the accumulated degree-days above 10°C (Champlain and Butler 1967), other climatic conditions, and availability of host plants (Kelton 1975). *Lygus lineolaris* (Palisot de Beauvois) has two generations in southern Manitoba (Timlick et al. 1993; Gerber and Wise 1995; Chapter III, Part 1). Nymphs of the first and second generations peak in abundance during the first half of June and early to mid August, respectively (Gerber and Wise 1995). Adult peaks occur in early to mid July and mid to late August for the first and second generations, respectively (Gerber and Wise 1995).

Seed alfalfa growers in southern Manitoba usually use an insecticide application in late June and another in the third week of August to suppress numbers of the first and second generation, respectively. In Saskatchewan (Murrell 1987) and Manitoba (Uddin 2005), an influx of lygus bugs has been observed after the second insecticide application, and has been attributed to the dispersal of adults from senesced and unsuitable hosts to alfalfa (Murrell 1987). Similar observations of influxes of adult lygus bugs into buckwheat in southern Manitoba in late August and early September (Elliott and Wise 2002; Wise et al. 2005) and seed alfalfa (Uddin 2005) triggered the research for this dissertation. Although there has been speculation about dispersal of these adults from desiccated hosts to buckwheat and seed alfalfa in late summer, no information is available on the sources, whether internal to the crop where nymphs develop or from other crops or wild hosts, of lygus bug adults that occur in late-season buckwheat and seed alfalfa fields.

Generally, herbivorous insects move as result of crowding, change in plant status that affects host plant suitability, unfavourable climatic conditions, or to escape from natural enemies (Rankin and Burchsted 1992). Lygus bugs are probably no exception, although their movements between different host plants are not well understood. Females of some lygus bug species move into economically important crops when both bugs (Otani 2000) and plants are reproductively active. These immigrant adults are likely to affect the receiving crops by direct feeding and oviposition which leads to nymphal feeding in the same year, or by being ready to oviposit on the crop in the following year resulting in feeding by the next generation (Painter 1929; Butts and Lamb 1990b; Otani 2000).

This chapter investigates the timing of movement and possible sources of lygus bugs arriving in seed alfalfa and buckwheat late in the growing season in southern Manitoba. I hypothesized that canola is the source of lygus bugs dispersal to buckwheat and seed alfalfa late in the growing season. These insect movements were studied in two ways. Firstly, intensive studies of seasonal changes in abundance were carried out in adjacent field plots of canola, seed alfalfa and buckwheat at the University of Manitoba Field Station at Carman, and secondly less intensive sampling was carried out in commercial fields of buckwheat and seed alfalfa in southern Manitoba. The relative abundance of adults and nymphs was measured to assess the timing of the generations, and infer probable influxes of adults from outside plots or fields.

Materials and Methods

Carman plots

Three adjacent field plots of buckwheat (cv. "Koto"), canola and seed alfalfa (triple plot) were established at the University of Manitoba Field Station at Carman in 2002 and 2003. Each plot measured 30 x 60 m in 2002 and 40 x 60 m in 2003. The canola was planted between the other two crops as it was considered to be a likely source of dispersing lygus bugs. Commercial methods of planting and standard rates of fertilizers were used in the three crops. The seed alfalfa plot was supplied with leaf-cutting bees, *Megachile rotundata* F., to insure pollination. No insecticide was applied to the seed alfalfa and canola but a portion of the buckwheat crop furthest from the canola was sprayed with insecticide in each year. Sweep net sampling of these plots was conducted at weekly intervals during the growing seasons.

On each sampling occasion in 2002, eight sets of ten 180° arc sweeps with a 40 cm diameter muslin net were taken along the two diagonals of the alfalfa and buckwheat plots and five sets were taken from the canola plot. This sampling started on 6 June, 2 July and 22 July, and ended on 23, 2 and 23 September 2002 for alfalfa, canola and buckwheat, respectively. To encourage insect dispersal, the canola was swathed on 19 August 2002, about 10-14 days before the surrounding canola crops on the station. After the canola dried, it was harvested on 3 September 2002. The insecticide, cyhalothrin-lambda 120g/L (Matador®), was applied at a rate of 83 ml product/ha using a tractor mounted sprayer at 200 L/ha to the outer 2/3 of the buckwheat plot on 30 July and subsequently four sample sets were taken in this plot only from the unsprayed section near the canola plot. Sweep net samples were transferred to sample bags which were transported in an insulated cooler to the laboratory, where they were frozen to kill and preserve the specimens. Lygus bug adults were identified to species using the keys of Kelton (1975, 1980), Schwartz and Foottit (1992a), and Mueller et al. (2003). Nymphs were identified to the genus level.

In 2003, the canola plot was swathed on 12 August, about two weeks before the surrounding canola, and harvested two weeks after that. Five sets of 10 sweeps were taken from each of the three crops using the same techniques as in 2002. During 2003, the sampling started on 21 May, 2 and 16 July, and ended on 22 September, 25 August and 22 September in alfalfa, canola and buckwheat, respectively. A Matador® application to the buckwheat plot was made as in 2002, except that half of the plot was sprayed and the application occurred on 28 July; after the application, only three sets of 10 sweeps were taken from the unsprayed section closest to canola in this plot.

In 2002, five Rothamsted design suction traps, manufactured by Burkard, UK, were deployed within the triple plot of alfalfa, canola and buckwheat (Fig. 1). A sixth trap (alfalfa 2) was deployed in a remote area of patchy alfalfa about 300 m from the plots (Fig. 1). Traps were operated for 2 days each week from late July to mid September, and operated continuously during the period from 12 – 20 August 2002. Each 2-day sample from each trap was placed separately in a plastic bag and then processed and identified according to the procedure used for sweep net samples.

Sampling in a commercial buckwheat field

In 2003, a trial was conducted to investigate the effects of lygus bugs population on yield parameters of buckwheat. In a commercial buckwheat field near Altamont, Manitoba (49° 23' 19" N, 98° 25' 15" W) sixteen plots, each measuring 20 x 30 m, were measured and marked by metal stakes about three weeks after seeding. Lygus bug populations were manipulated in 12 of the plots by applications of the insecticide. For the purpose of investigating the dispersal of lygus bug adults to buckwheat late in the growing season, samples from field plots that did not receive any insecticide applications were used. This treatment was replicated in four plots and represented the natural population of lygus bugs. There were two adjacent canola fields, one to the north and one to the east; each was about 200 m from the plot location. There was another canola field across a gravel road, about 150 m from the plot location, without any shelter belt between the field and the road.

At weekly intervals from the start of flowering (16 July 2003) until the time of harvest (23 September 2003), a sample of ten 180° arc sweeps was taken along the diagonal of each plot using a sweep net. Samples were processed as for the Carman plots.

Sampling in commercial seed alfalfa fields

In 2002-2004, trials were conducted to investigate the effects of late season populations of plant bugs on the yield of commercial alfalfa cultivated for seed production. In these trials, plant bug populations were manipulated in selected plots using applications of insecticide. To investigate the dispersal of lygus bug adults to seed alfalfa late in the growing season, only field plots in those trials that did not receive insecticide were sampled.

In 2002, the control (unsprayed) treatment was replicated in three plots, each 20 x 30 m, in a field near Teulon. A sample of ten 180° arc sweeps was taken along the diagonal of each plot using a sweep net at weekly intervals from 29 August 2002 until the crop was harvested on 29 September 2002. These plots were sampled only after an insecticide application to adjacent plots on 29 August. For two weeks before this date, five sweep net samples were taken at weekly intervals in an adjacent 20 x 30 m plot. Samples were processed as for the Carman plots. The field was isolated from the south and west sides by a dense shelter belt of trees, and exposed to a gravel road and grazing area to the north, and highway on the east side. There were no canola fields were within 1.6 km.

In 2003, the trial was located in a commercial seed alfalfa field near Riverton, MB (97° 7' 11" W, 50° 57' 2" N). There were canola fields were adjacent to the south and west of the alfalfa, each about 400 m from the plots. In 2004, the field was near Arborg (97° 22' 48" W, 51° 2' 42" N), and was surrounded by dense shelter belts, beyond which was an area of bare soil area except at its entrance, which led to an area of patchy alfalfa, without any canola within a 6 km radius. Sweep net samples were taken along the diagonal of each plot at weekly intervals from 7 August to 11 September in 2003 and 17 August to 23 September in 2004. In both 2003 and 2004, there were four replicates, and sampling terminated when the crop was desiccated. Samples were processed as described above.

Results

Carman plots

In alfalfa in 2002, catches of lygus adults and nymphs were similar except between 11 June and 8 July when nymph catches were 4-12 times the catches of adults (Fig. 2). The peak of adult catches from 15-29 July occurred towards the end of a broader peak of nymphs (Fig. 2). A small increase in the numbers of adults and nymphs occurred in seed alfalfa in the week following canola swathing but not following the harvest (Fig. 2). In 2003, two peaks of lygus nymphs occurred during, June and August, followed by peaks of adults (Fig. 3). The late peak of adults continued through the end of growing season averaging approximately 4 to 11 times nymph catches during the period of 25 August to 8 September (Fig. 3). Insect numbers decreased sharply during the second half of September with the decrease of temperature.

The lygus bug numbers in the canola plot in 2002 and 2003 were characterized by a peak of adults in July followed by a peak of nymphs in August (Fig. 4 & 5). Catches in the last two weeks of both trials were of insects in the drying swath on the ground. In both years lygus bugs bugs decreased after swathing (Fig. 4 & 5), except for the adults in 2003 (Fig. 5).

In the buckwheat field plot at Carman in 2002, lygus bug adults and nymphs gradually increased after the swathing of the adjacent plot of canola (Fig. 6). The canola was completely dry and was harvested on 3 September 2002, and the numbers of both nymphs and adults caught in the buckwheat plot on 9 September 2002 were about twice that caught just before the harvest of canola (Fig. 6). In 2003, the numbers of lygus bug adults were higher in the weeks after swathing canola than in the preceding weeks except for the week of 1 September 2003 when heavy rain just before sampling affected sampling efficiency (Fig. 7). Nymphs peaked during August then decreased in numbers during the time of swathing and harvesting canola (Fig. 7).

Generally, catches of suction traps were low. After the swathing of canola, the total trap catch at the middle of the canola plot was the lowest, consistent with the low catch in sweep samples. The traps between alfalfa and canola plots, in the remote alfalfa area and at the edge of buckwheat caught more lygus bugs than those at the edge of alfalfa plot and the one between the canola and buckwheat plots (Fig. 8). All the adult mirid plant bugs caught in these traps were *L. lineolaris* except for one *L. borealis* and one *L. elisus*. The total number of lygus bugs caught by the traps was higher at the beginning and the end of the period of trap operation (Fig. 9). Traps in different locations had similar patterns of catches, except the remote alfalfa trap which had the highest catches late in the growing season and the canola trap which had the highest catches early in the growing season (Fig. 10). Sweep net catches of adults in the buckwheat in 2002 (Fig. 6) were the highest between 9 and 16 September 2002, just after canola harvest, these high catches were synchronized with the highest peak of buckwheat suction trap catches (Fig. 10).

Commercial buckwheat

The catches of adults in buckwheat showed invading adults peaking at the end of July, followed by a single generation produced in the crop (Fig. 11). The nymphs peaked in mid August, followed by a large peak of adults in September (Fig. 11). The canola fields adjacent to the commercial buckwheat field sampled in 2003 were harvested during the week 19-24 August. The number of lygus bug adults in samples from the buckwheat field after the combining of nearby canola fields reached over four times the number before canola harvest (Fig. 11). The numbers of adults collected after 18 August were more than four times the number of nymphs collected in the field.

Commercial seed alfalfa

In the commercial fields of seed alfalfa, only late season populations were sampled. Catches were generally low in August 2002 (Fig. 12) and mean numbers did not exceed 6.4 insects/10 sweeps, except during the first week of September, approximately a week after the combining of nearby canola fields in the area (Fig. 12). An increase in adult catch was also recorded in 2003 following the harvest of adjacent canola fields in the week of 14-20 August, 2003 (Fig. 13). In 2002 and 2003, the number of adults in alfalfa in late August or early September greatly exceeded the numbers of nymphs. Unlike 2002 and 2003, in 2004, adult catches were higher than nymph catches during the whole sampling period (Fig. 14). Mean catches of nymphs declined throughout late August and the first 3 weeks of September (Fig. 14).

Discussion

Identifying the sources, whether locally produced or migrantexternally produced, of the large populations of *L. lineolaris* that occur late in the growing season in seed alfalfa and buckwheat was the main objective of this part of the research. The data showed that lygus bugs can complete two generations in seed alfalfa, and one generation in both buckwheat and canola. These results agree with those of Gerber and Wise (1995); Leferink and Gerber (1997); Uddin (2005) and Wise et al. (2005). The weak peak of the second generation in the seed alfalfa plot near Carman might be because the plot was seeded in 2002, making the timing of first flowering similar to that of canola.

The first generation produced in the crop appeared in mid June in alfalfa not in its first year, late July in canola and late August in buckwheat. These observations are consistent with the synchronization of the generations with the flowering or early seed production stages of the three plants.

I hypothesized that the influx of *L. lineolaris* adults to seed alfalfa and buckwheat crops late in the growing season is the result of dispersal from senesced nearby canola crops. The plots at Carman in 2002 and 2003 were designed to mimic a production system including the hypothesized source crop, canola, and the recipient crops, seed alfalfa and buckwheat. Early swathing of canola was conducted to cause early dispersal that might be distinguished from later dispersal from nearby commercial canola.

In the alfalfa plots at Carman,the adult peaks lagging a peak of nymphs were consistent with one generation in alfalfa in 2002 and two generations in 2003. The small peak in late August 2002 may reflect a partial second generation or an influx from outside the plot. The extended peak of adults in September 2003 may reflect an influx of adults augmenting locally produced adults.

In the canola plots, the first peak of adults represented invading adults that probably oviposited in the crop, leading to a single complete generation in the crop. In both years the number of nymphs developing in early August greatly exceeded the number of subsequent adults, which were maturing as the crop was in swath or being harvested. The relatively small number of late season adults is consistent with the hypothesis that they are leaving the canola swath at this time. The lack of an early September peak of Adults in this field in consistent with the lack of nearby canola which might have provided a source of dispersing adults.

In the buckwheat plots, a small peak of adults and absence of nymphs in late July indicated an invasion of adults synchronized with the blooming of the crop. The peaks in late August and early September in both years suggested one generation, and the large number of adults compared with nymphs suggested dispersal from sources outside the plot.

The experiment was conducted at an experimental station where various crops were cultivated on a small scale, and some areas were left fallow allowing weeds to grow. Most of these crops and weeds are hosts of lygus bugs and were found within a short distance from the plots. *Lygus lineolaris* adults were found in large numbers on these hosts, especially weeds along the edges of plots (Personal observation). The close proximity of many patches of diverse hosts may have resulted in movements of lygus bugs among the different host crops and weeds, including my plots, with some degree of preference toward more suitable hosts. Suction trap sampling did not produce convincing evidence to support my hypothesis that canola is a major source of dispersing adults, despite the fact that trap catches reflected the peaks of the populations of adults.

The traps showed adults disperse actively early and late in the season, but the diversity of nearby hosts prevented establishing which hosts are the main sources of the dispersers. It was evident that adults from external sources invaded buckwheat around the third week of August. Sweep net sampling in buckwheat showed that this crop is more prefered by lygus bugs than alfalfa under the conditions at the Carman experimental station.

The situation in the commercial fields was different when large acreages of canola were adjacent to either buckwheat or seed alfalfa fields. The sweep net catches detected the influx of lygus bug adults in the commercial buckwheat field, and in seed alfalfa fields with adjacent canola, shortly after the harvest of canola. In one commercial alfalfa field in 2004, there was no evidence of an influx, probably linked to the isolation of the field from any nearby canola or other source of lygus bugs at this time. The same isolation from canola occurred in 2002, but there were some pastures with lygus bug hosts near the 2002 field. Another difference in 2004 was the low temperatures in August of that year (Appendix I). The low temperatures may have inhibited flight, which is initiated at temperatures over 10°C (Champlain and Butler 1967), at the time lygus bugs were being forced out of canola. Heavy rain was responsible for the low catch on 1 September. These observations are consistent with a single late generation of lygus in the crop, augmented by a late-season influx of lygus from elsewhere.

Generally, it seems the dispersal of lygus bugs into buckwheat is larger than that into seed alfalfa late in the growing season. This is probably because buckwheat at this time of the season is a more suitable host for lygus adults than is a seed alfalfa. With their preference for meristematic and reproductive plant tissues, lygus bugs probably prefer and move into buckwheat, which continues flowering until the end of the season, while the maturity of the alfalfa crop at the time of canola senescence may discourage retention of lygus adults in seed alfalfa.

The results from sweep net sampling in the commercial fields of seed alfalfa and buckwheat showed a shrap increase of lygus bug adults after the harvest of nearby canola crops, which agreed with the hypothesis that canola is the a major sources of late season emigrant lygus bugs to seed alfalfa and buckwheat. The fields of seed alfalfa and buckwheat during this research were bordered with large acreage of canola with no other crops in a radius exceed 4 km in all trials. However, the triple plot study at Carman did not provide similar a clear result, partly perhaps because of the nature of the experimental station which full of many different alternative host plants of lygus bugs in proximity distancethe vicinity. Furthermore, mMany weed and wild hosts of lygus bugs in the station had high population of lygus bugs before and after the harvest of canola (Personal observation) suggesting that these hosts are playing an important role in the life cycle of lygus bugs.

Fig. 1: Layout of the plots of alfalfa, canola and buckwheat at Carman Field Station in 2002 with the suction trap locations. The suction traps from left to right are: alfalfa, alfalfa/canola, canola, canola/buckwheat and buckwheat. The arrow shows the direction of a trap located 300 m away.

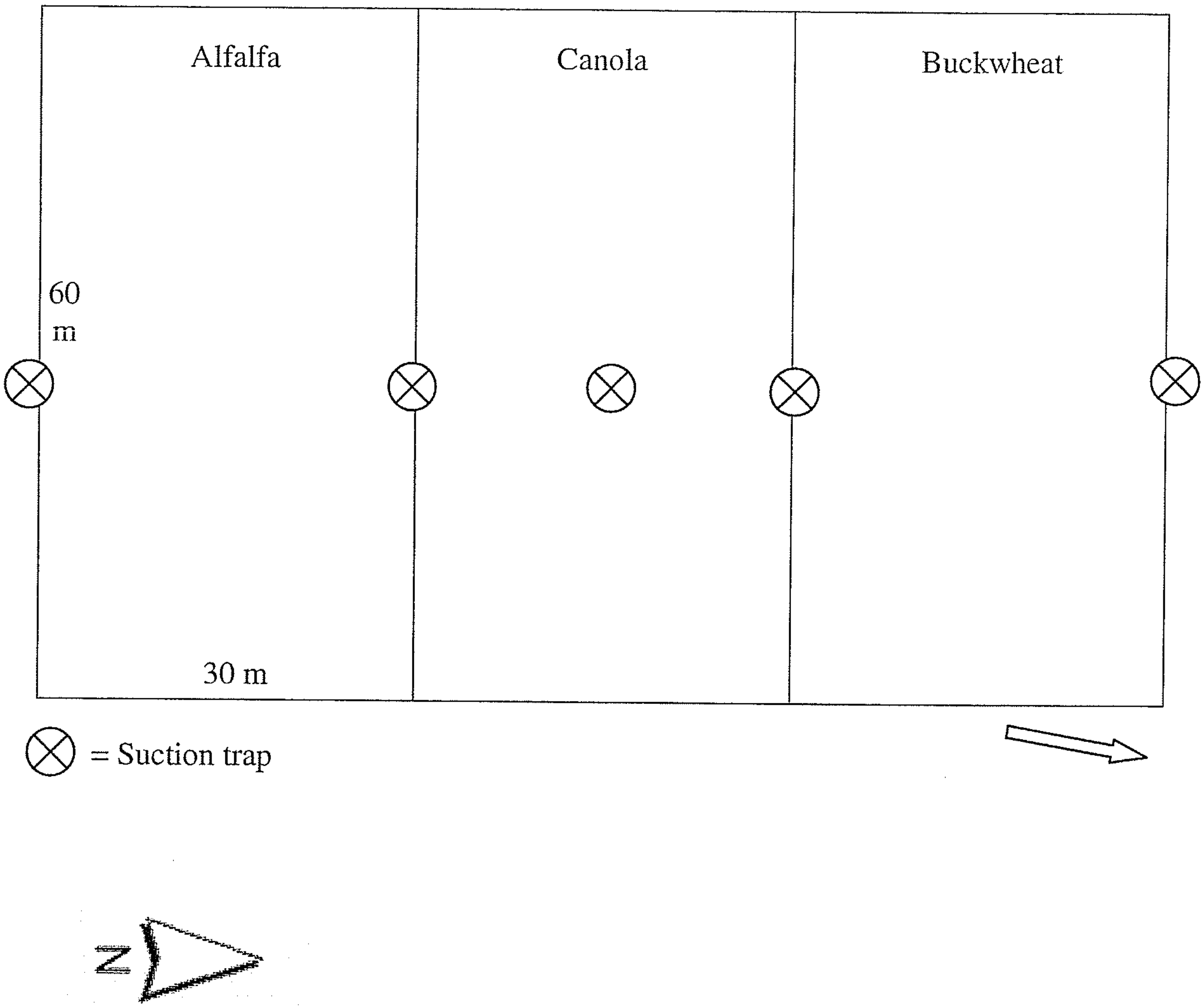

Alfalfa
Canola
Buckwheat
60 m
30 m
= Suction trap
N

Fig. 2: Mean (±SEM) catches of lygus bug adults and nymphs from the alfalfa plot at Carman, MB in 2002. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date.

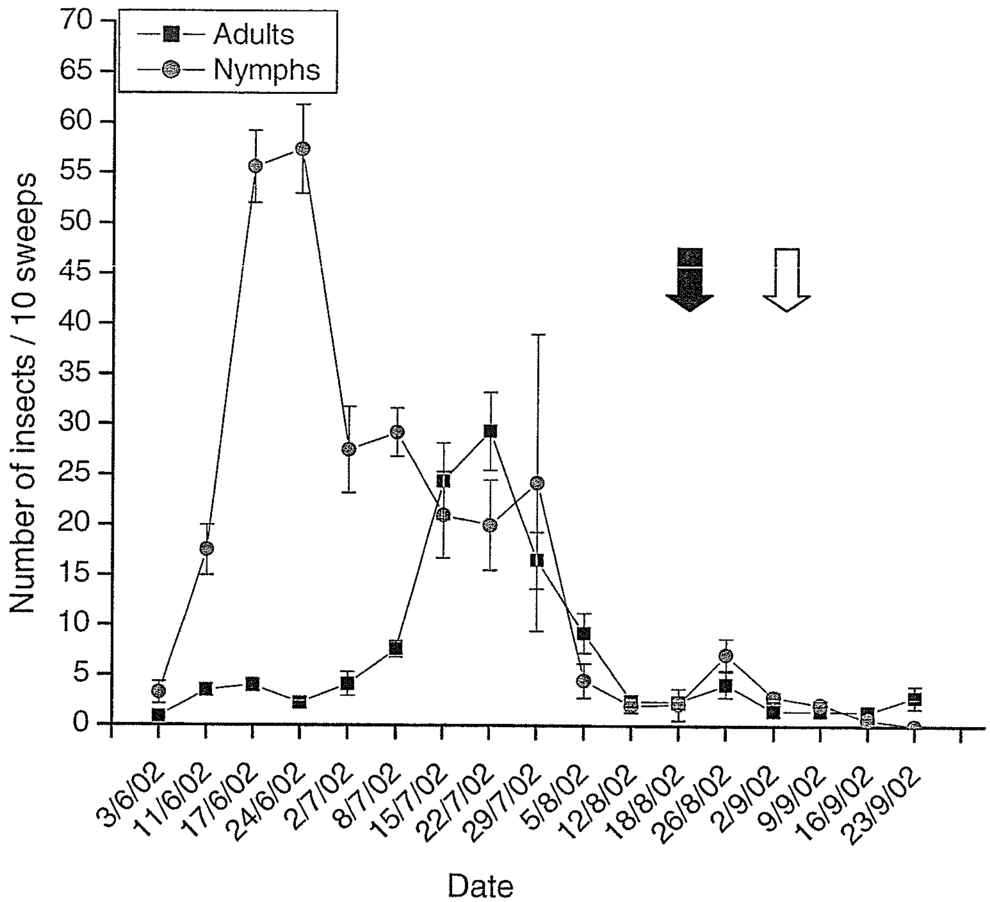
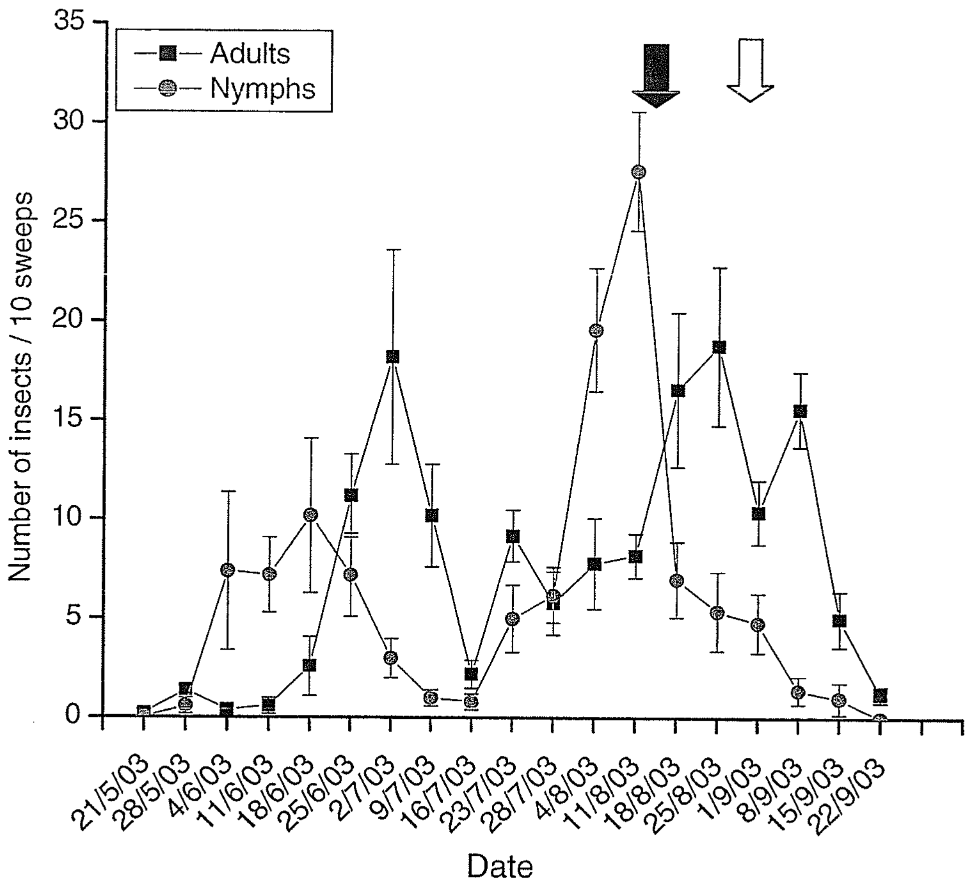

Adults
Nymphs
Number of insects / 10 sweeps
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
3/6/02
11/6/02
17/6/02
24/6/02
2/7/02
8/7/02
15/7/02
22/7/02
29/7/02
5/8/02
12/8/02
18/8/02
26/8/02
2/9/02
9/9/02
16/9/02
23/9/02
Date

Fig. 3: Mean (±SEM) catches of lygus bug adults and nymphs from the alfalfa plot at Carman, MB in 2003. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date.



Adults
Nymphs
Number of insects / 10 sweeps
0
5
10
15
20
25
30
35
21/5/03
28/5/03
4/6/03
11/6/03
18/6/03
25/6/03
2/7/03
9/7/03
16/7/03
23/7/03
28/7/03
4/8/03
11/8/03
18/8/03
25/8/03
1/9/03
8/9/03
15/9/03
22/9/03
Date

Fig. 4: Mean (±SEM) catches of lygus bug adults and nymphs from the canola plot at Carman, MB in 2002. Arrow denotes the date of swathing of the canola plot.

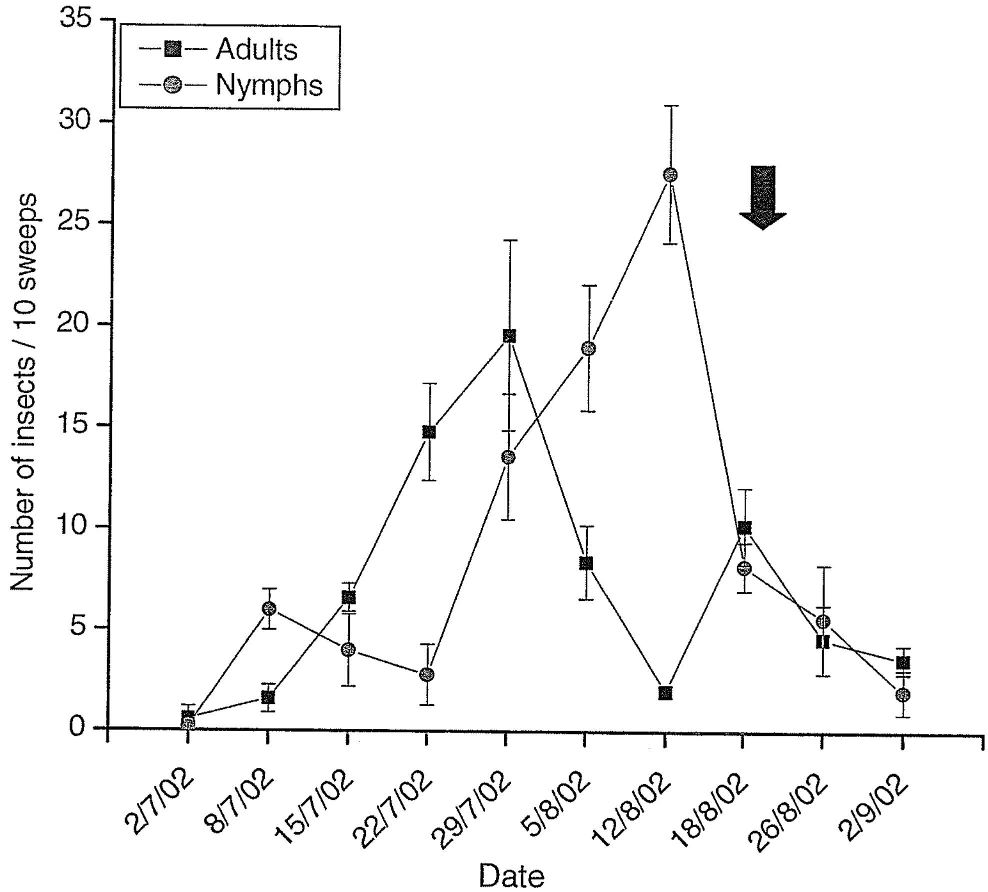
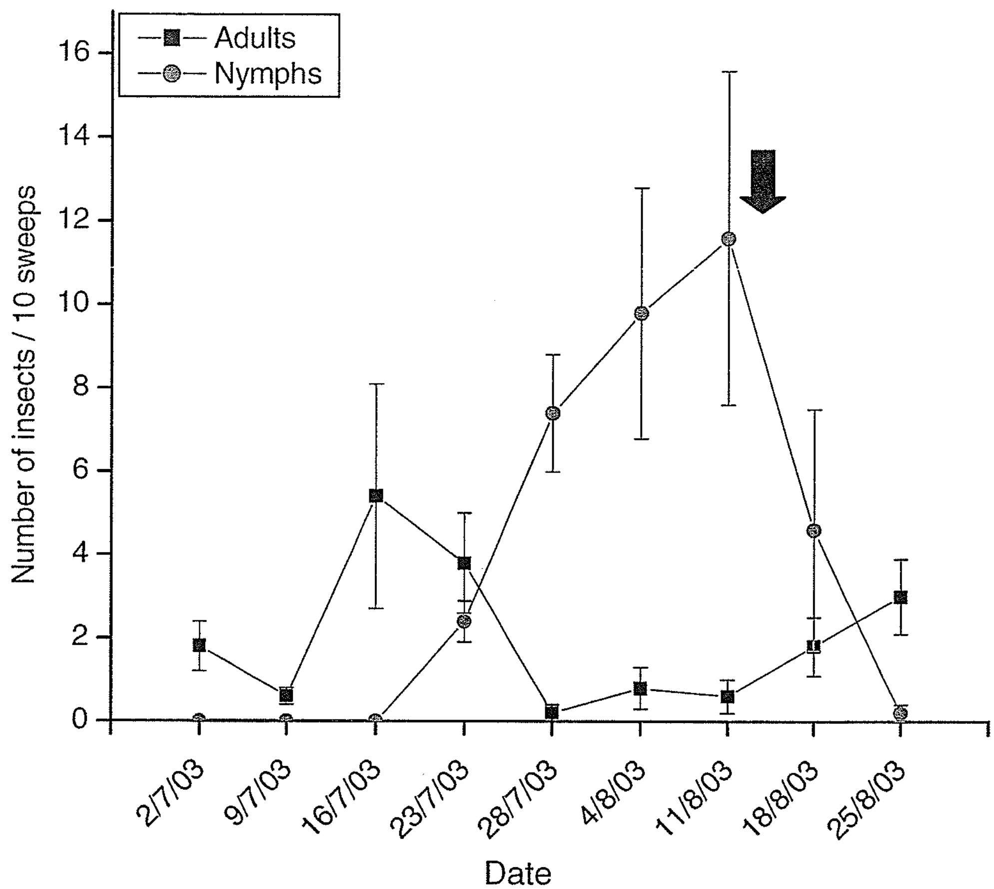
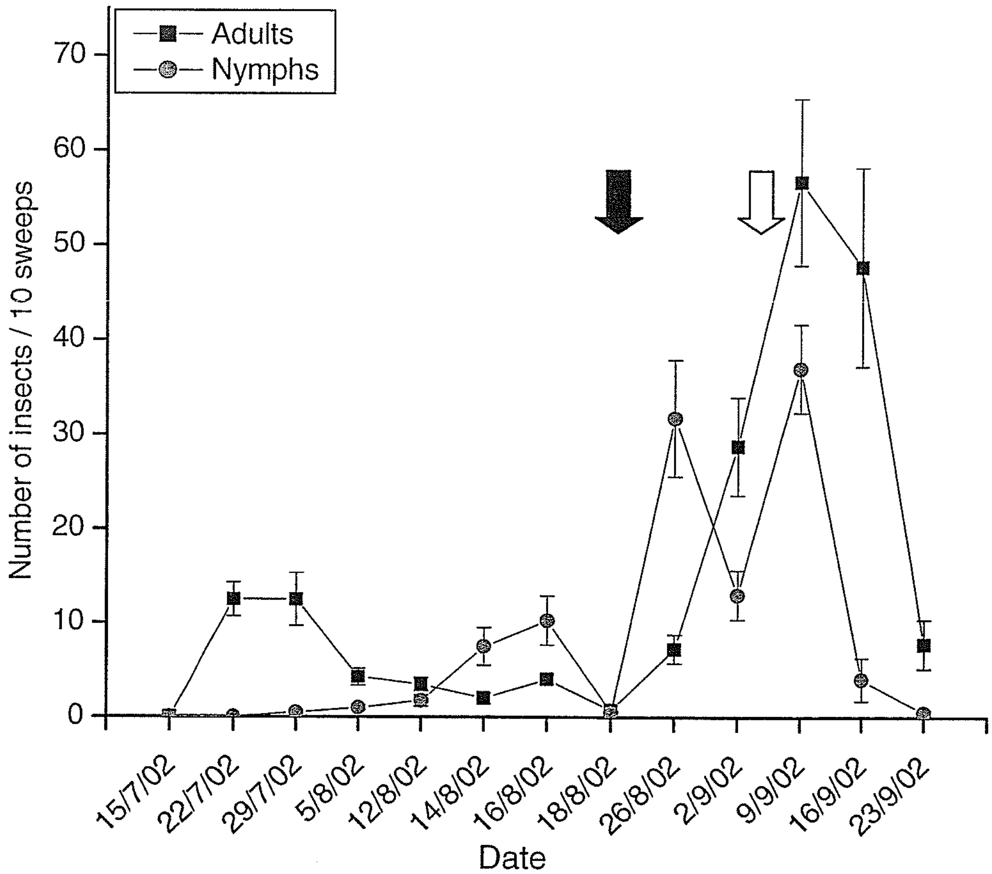

Adults
Nymphs
35
30
25
20
15
10
5
0
Number of insects / 10 sweeps
2/7/02
8/7/02
15/7/02
22/7/02
29/7/02
5/8/02
12/8/02
18/8/02
26/8/02
2/9/02
Date

Fig. 5: Mean (±SEM) catches of lygus bug adults and nymphs from the canola plot at Carman, MB in 2003. Arrow denotes the date of swathing of the canola plot.



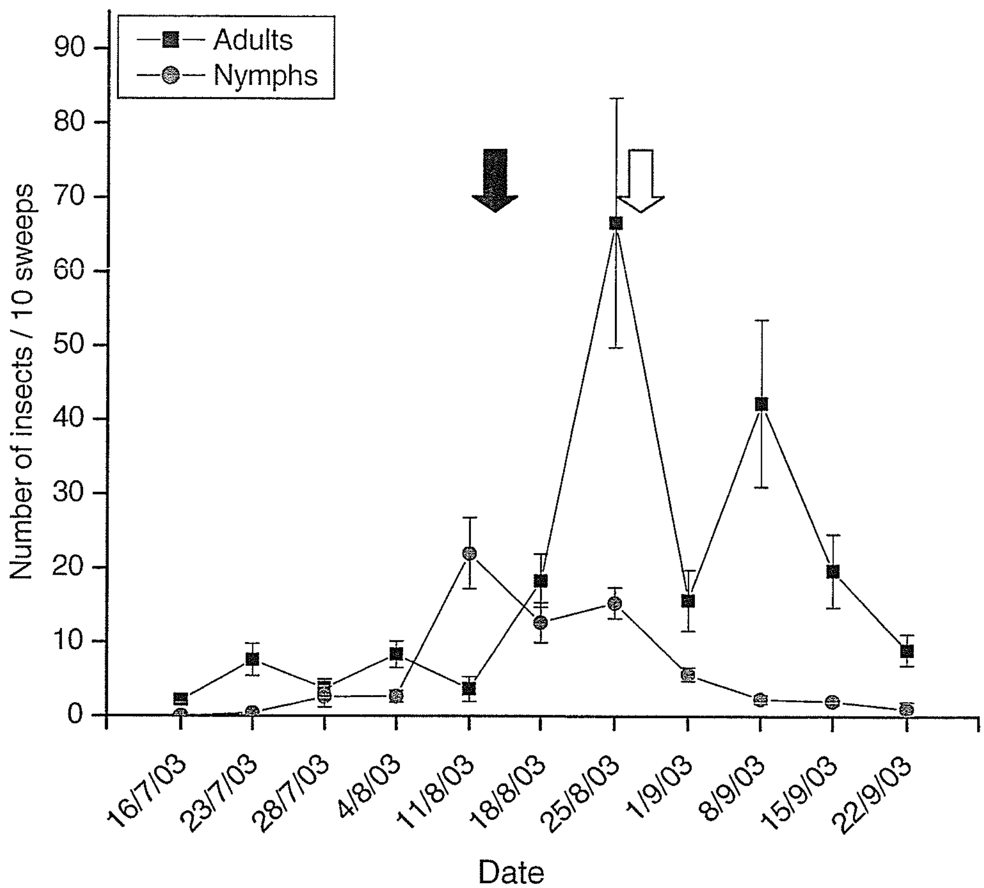
Adults
Nymphs
Number of insects / 10 sweeps
0
2
4
6
8
10
12
14
16
2/7/03
9/7/03
16/7/03
23/7/03
28/7/03
4/8/03
11/8/03
18/8/03
25/8/03
Date

Fig. 6: Mean (±SEM) catches of lygus bug adults and nymphs in a buckwheat plot at Carman, MB in 2002. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date.



Adults
Nymphs
Number of insects / 10 sweeps
70
60
50
40
30
20
10
0
15/7/02
22/7/02
29/7/02
5/8/02
12/8/02
14/8/02
16/8/02
18/8/02
26/8/02
2/9/02
9/9/02
16/9/02
23/9/02
Date

Fig. 7: Mean (±SEM) catches of lygus bug adults and nymphs in a buckwheat plot at Carman, MB in 2003. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date.



Adults
Nymphs
Number of insects / 10 sweeps
90
80
70
60
50
40
30
20
10
0
16/7/03
23/7/03
28/7/03
4/8/03
11/8/03
18/8/03
25/8/03
1/9/03
8/9/03
15/9/03
22/9/03
Date

Fig. 8: Total catches of lygus bugs by suction traps after swathing canola, 20 August to 18 September, in plots at Carman in 2002.

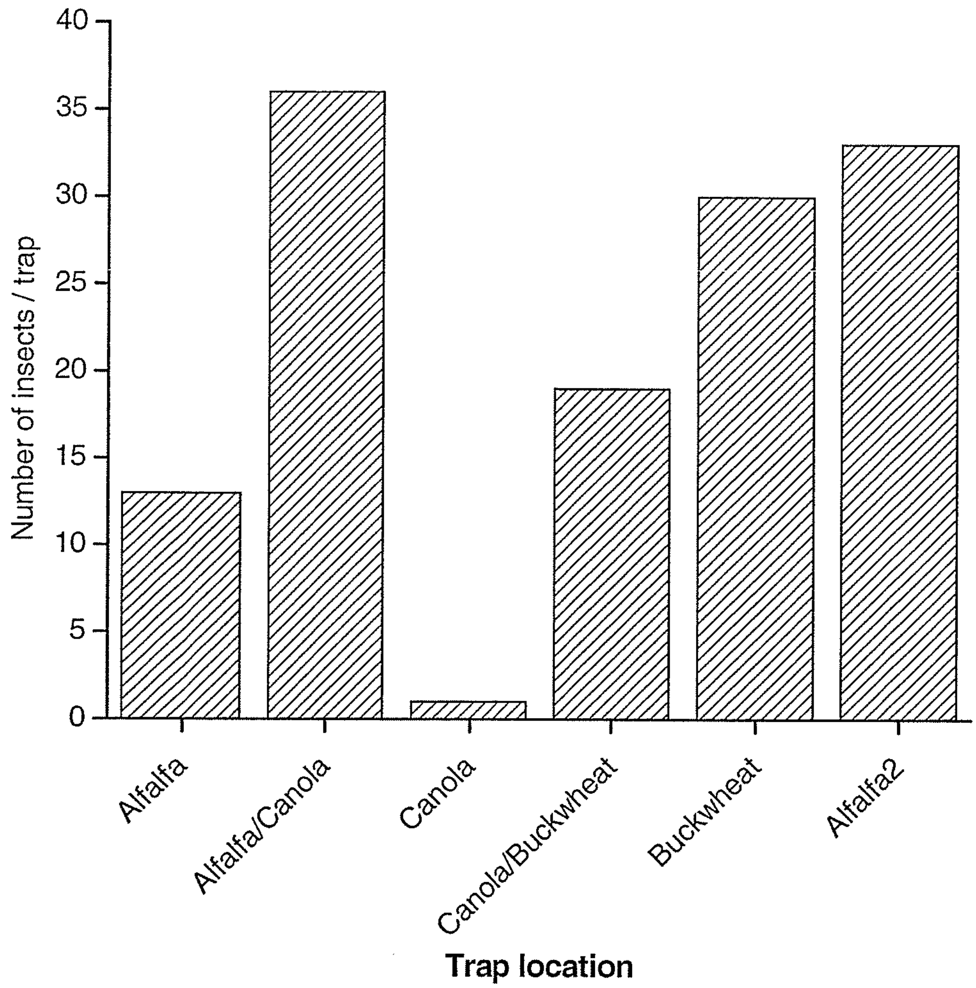
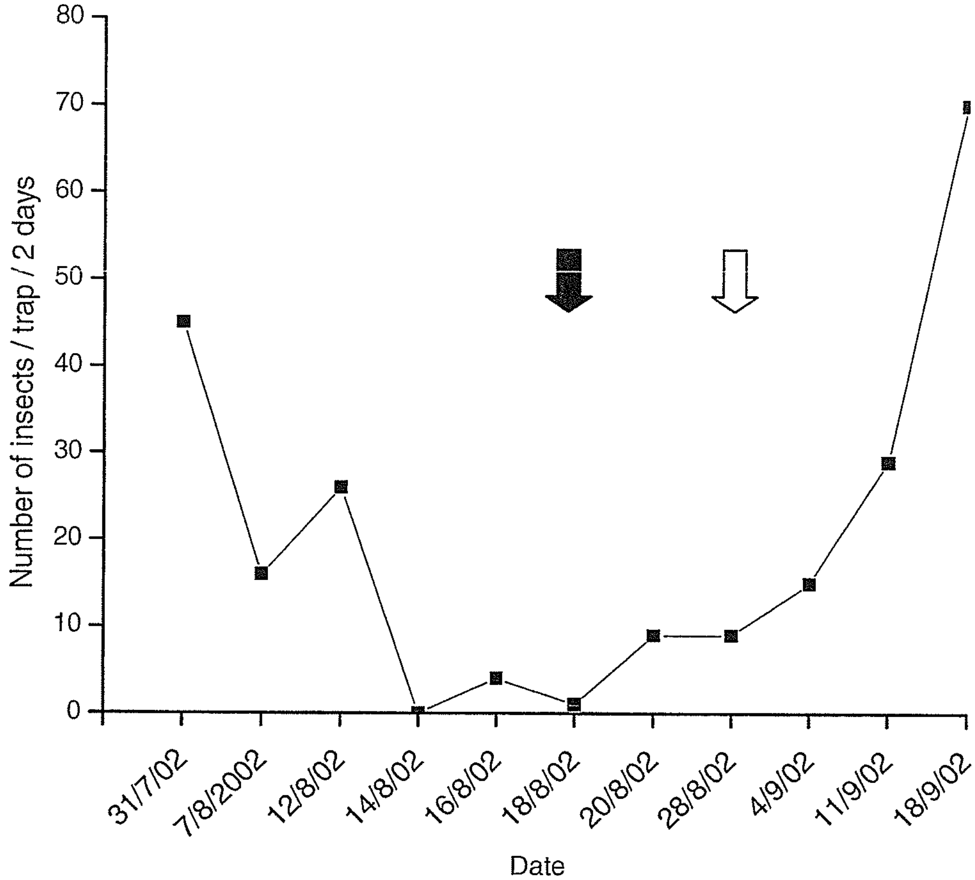

40
35
30
25
20
15
10
5
0
Number of insects / trap
Alfalfa
Alfalfa/Canola
Canola
Canola/Buckwheat
Buckwheat
Alfalfa2
Trap location

Fig. 9: Total catches of all suction traps during the entire period of operation at Carman in 2002. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date.



80
70
60
50
40
30
20
10
0
Number of insects / trap / 2 days
31/7/02
7/8/2002
12/8/02
14/8/02
16/8/02
18/8/02
20/8/02
28/8/02
4/9/02
11/9/02
18/9/02
Date

Fig. 10: Total catches of each suction trap during the entire operating period in plots at Carman in 2002. Black arrow denotes canola swathing date and white arrow denotes canola harvesting date. AlfaCan = Alfalfa/Canola; CanBuck = Canola/Buckwheat.

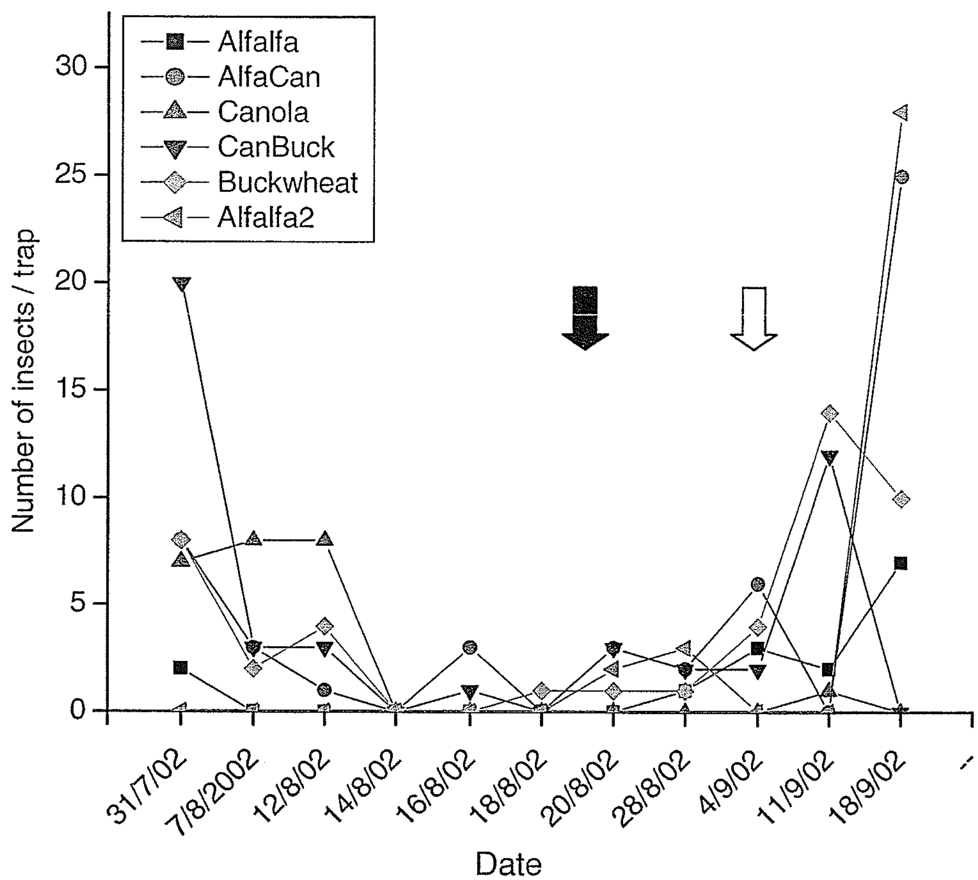

Alfalfa
AlfaCan
Canola
CanBuck
Buckwheat
Alfalfa2
30
25
20
15
10
5
0
Number of insects / trap
31/7/02
7/8/2002
12/8/02
14/8/02
16/8/02
18/8/02
20/8/02
28/8/02
4/9/02
11/9/02
18/9/02
Date

Fig. 11: Mean (±SEM) catches of lygus bug adults and nymphs from buckwheat at Altamont, MB in 2003. White arrow denotes the date of harvesting of adjacent canola fields.

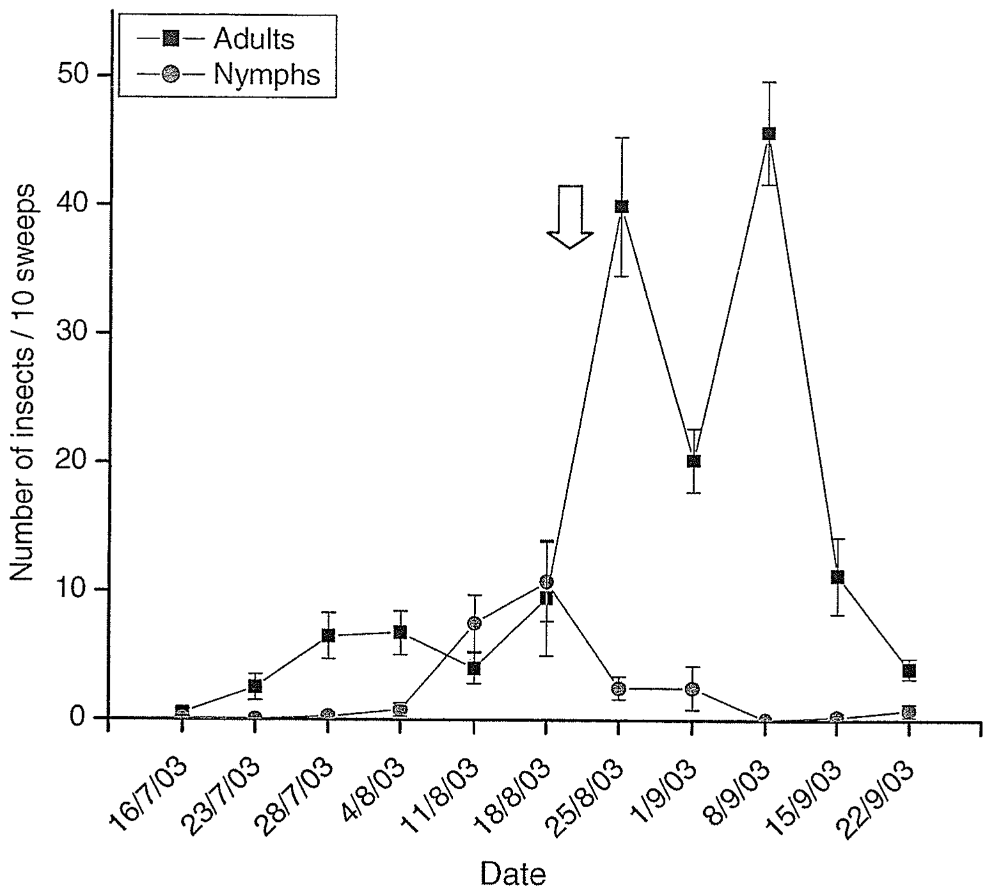

Adults
Nymphs
50
40
30
20
10
0
Number of insects / 10 sweeps
16/7/03
23/7/03
28/7/03
4/8/03
11/8/03
18/8/03
25/8/03
1/9/03
8/9/03
15/9/03
22/9/03
Date

Fig. 12: Mean (±SEM) catches of lygus bug adults and nymphs from seed alfalfa at Teulon, MB in 2002. White arrow denotes the date of harvesting of nearby canola fields.

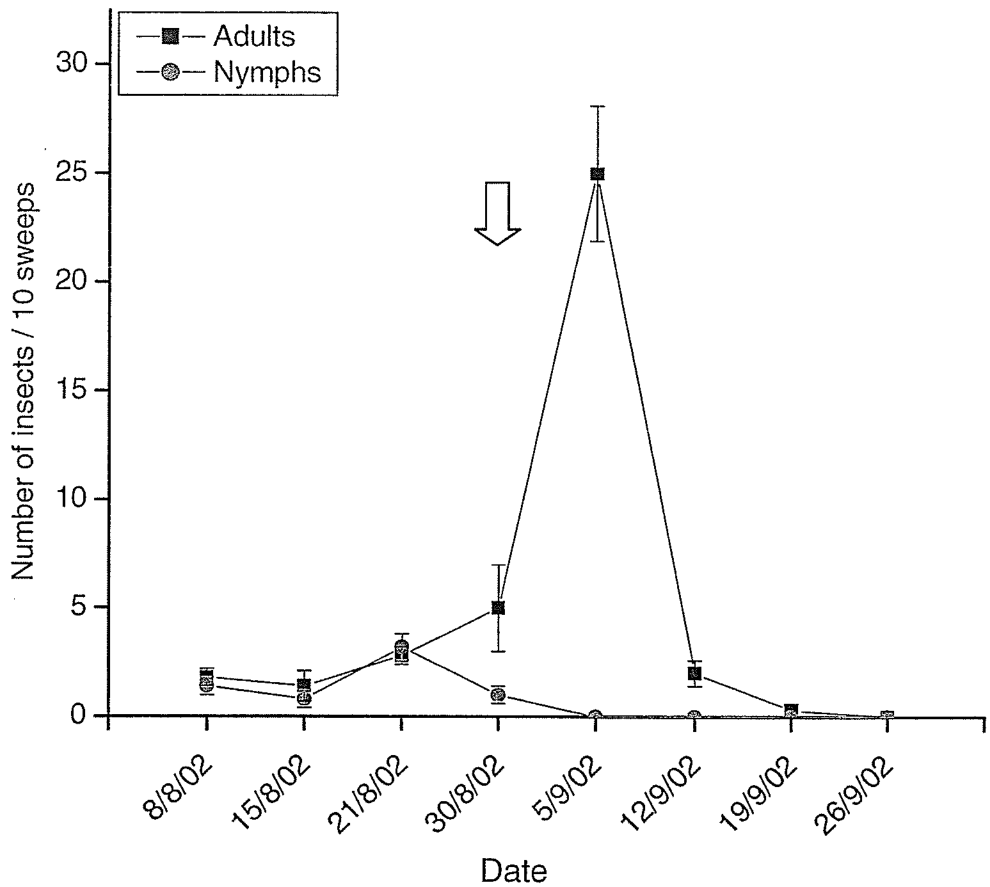

Adults
Nymphs
Number of insects / 10 sweeps
30
25
20
15
10
5
0
8/8/02
15/8/02
21/8/02
30/8/02
5/9/02
12/9/02
19/9/02
26/9/02
Date

Fig. 13: Mean (±SEM) catches of lygus bug adults and nymphs from seed alfalfa at Riverton, MB in 2003. White arrow denotes the date of harvesting of adjacent canola fields.

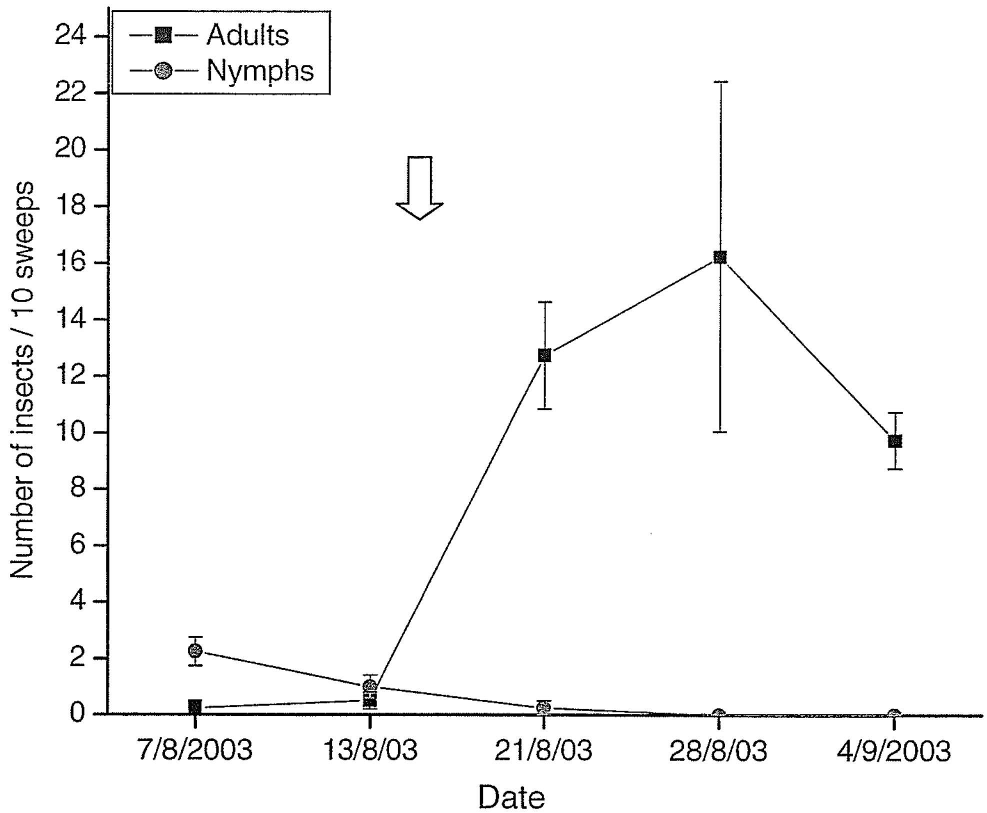
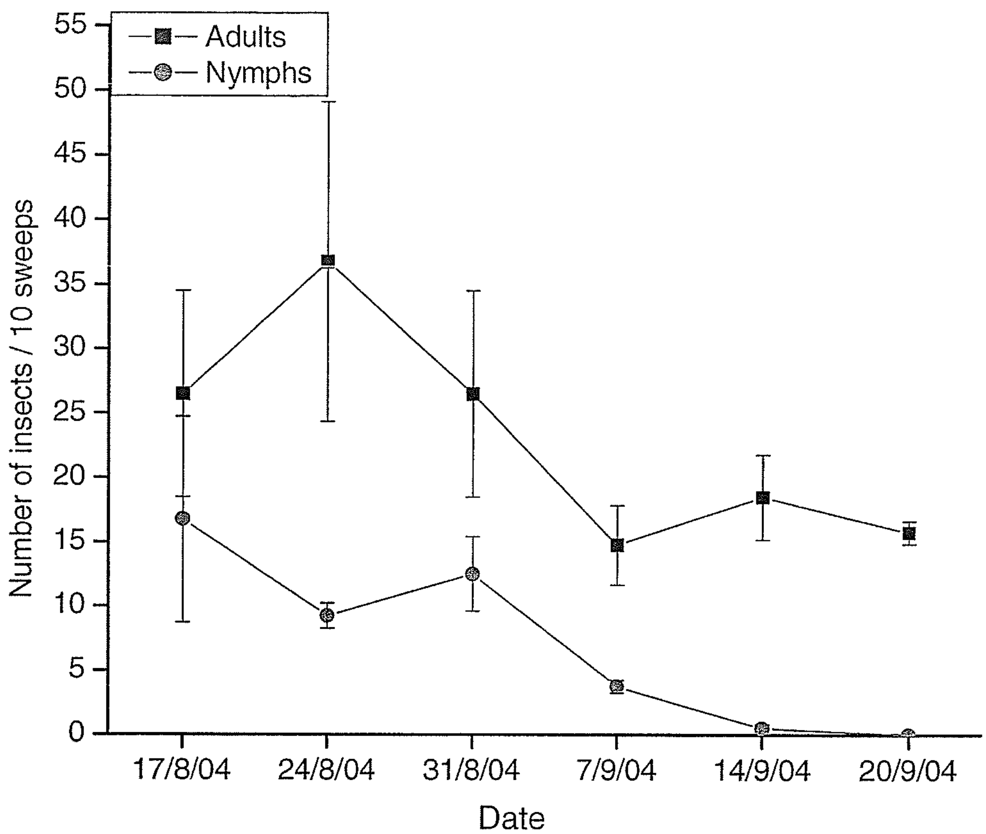

Adults
Nymphs
Number of insects / 10 sweeps
24
22
20
18
16
14
12
10
8
6
4
2
0
7/8/2003
13/8/03
21/8/03
28/8/03
4/9/2003
Date

Fig. 14: Mean (±SEM) catches of lygus bug adults and nymphs from seed alfalfa at Arborg, MB in 2004.


Adults
Nymphs
Number of insects / 10 sweeps
55
50
45
40
35
30
25
20
15
10
5
0
17/8/04
24/8/04
31/8/04
7/9/04
14/9/04
20/9/04
Date

CHAPTER III – PART 3

Implications of lygus bugs for buckwheat yield in southern Manitoba

Abstract

In southern Manitoba, small numbers of adult *Lygus lineolaris*, usually less than 10 adults / 10 sweeps, appear on buckwheat crops in late July where they reproduce and give rise to nymphs that mature in August. In September, large adult populations appear (can exceed 60 adults / 10 sweeps), likely a mix of adults that developed in the crop along with adults that disperse from neighboring senescent host plants. An insecticide application in late July or early August resulted in yield increases ranging from 12-78% in five different trials over three years, whereas applications in September did not significantly affect yield. Caged buckwheat plants were much more severely damaged by lygus bug nymphs than adults, and the flowering stage was more vulnerable than later stages with developing seed. Nymphs attacking plants during flowering significantly decreased seed weight, flower and seed numbers; damage by nymphs increased percentages of dry flowers and shriveled seeds. In big the cages, nymphs reduced yield by 74%. This reduction in yield can largely be broke up attributed to a 55% is the result of reduction in the number of flowers due to bud abortion and flower drying. This percentage approaches the percentage reduction in number of seeds, which iswas 67%. The 12% difference between 55% the reduction in flower number and 67% reduction that in seed number could be attributable to seed abortion. The difference between the 67% reduction in the number of seeds and the 74% reduction in total seed yield in the cage could be attributable to reduced seed weight, as the percentage of shrivelled seed in the presence of nymphs was increased by 67%.

In two trials of the fungal pathogen, *Beauveria bassiana*, applied as an insecticidal formulation against adults in September, fungal infection of bugs was significantly higher in treated plots, although the number of bugs in treated and control plots did not differ. Buckwheat seed yield was increased in the *B. bassiana* treatment in one of the two years, most probably due to decrease lygus bug feeding as a result to the increase of fungal infection.

Introduction

Mirid plant bugs can destroy or reduce the yield of grain, seed, vegetable and fruit crops throughout the world (Kelton 1980). Plant bugs in the genus *Lygus* are primarily pests of cotton, coffee, alfalfa, beans, carrots and several crops grown for seed (Strong et al. 1970). Thirty-four species of *Lygus* are known from North America, of which 22 occur in the Prairie Provinces of Canada (Kelton 1980). At least nine species of the genus *Lygus* are of major importance to agriculture in North America, Europe and Asia (Kelton 1975). In Canada, lygus bugs feed on the sap of new growth and reproductive tissues of many host plants such as alfalfa (Gupta et al. 1980), canola (Lamb 1989; Jones 2000), lentil, potato, strawberry (Mailloux and Bostanian 1988) and bean (Khattat and Stewart 1975; Stewart and Khattat 1980a & b). On the Canadian Prairies *Lygus* spp. are major pests of alfalfa (Craig 1983; Uddin 2005) and canola (Butts and Lamb 1991a) and the most common species found on these crops are *L. elisus* (Van Duzee), *L. borealis* (Kelton), and *L. lineolaris* (Palisot de Beauvois) (Craig 1983; Butts and Lamb 1990a & b; Leferink 1992; Wise and Lamb 1998a; Otani 2000). *Lygus lineolaris* is the most abundant species in Manitoba (Timlick et al. 1993).

Buckwheat, *Fagopyrum esculentum* Moech., has been cultivated in Manitoba since the early settlers from Ukraine brought its seeds to the province. Manitoba produces about 70% of Canadian buckwheat and the provincial crop occupied about 10,000 ha and 4,000 ha in 2004 and 2005, respectively (Manitoba Agriculture, Food and Rural Initiatives 2004 & 2005). Until recently, insect pests were not considered an important problem of buckwheat production in Canada, and thus there are no registered insecticides for use on buckwheat. During the past few years, large numbers of adult lygus bugs have been observed in Manitoba buckwheat fields near the end of the growing season, with numbers reaching 15 adults per one sweep in some fields in 2001 (Elliott unpublished). Immature lygus bugs occur on buckwheat earlier in the season (Elliott and Wise 2002). Thus, it appears that there is a reproductive population of lygus bugs in buckwheat crops in the summer, which may be augmented near the end of the season by adults dispersing from other hosts. The large number of adults late in the season caught the attention of growers and extension workers, who wanted information about the implications of these populations for buckwheat yield. This research project started from the very basic question; what do lygus bugs do to the buckwheat crop? The next step was to investigate the relationship between the lygus bug and the buckwheat crop as a host plant. Finally, information was needed on the most appropriate management technique, if needed. The objectives of this chapter are to determine whether lygus bugs have any effects on the yield of buckwheat in Manitoba, and if so, to construct an economically-based control decision criterion for these insects on buckwheat. To achieve these objectives, the effect of lygus bugs on yield of buckwheat was investigated during the summers of 2002-2004. Insecticide applications and field-cage enclosures were used to expose buckwheat plants to different numbers of lygus bugs.

Materials and Methods

Insecticide application and caged flower heads trial

As nothing was known about the pestiferous nature of lygus bugs on buckwheat at the beginning of this research, a preliminary trial was designed to determine whether lygus bugs have any effect on buckwheat, and if so to determine what measurements would be most useful for quantifying the effect.

In 2002, a 60 x 30 m field plot of buckwheat (cv. "Koto") was established at the University of Manitoba Field Station, Carman. The plot was flanked on one side by canola, grown to provide a source of late season lygus bugs. Production practices in the buckwheat plot followed the norm for commercial production. The plot was treated with herbicide and tilled before seeding. The plot was seeded at a rate of 45 kg/ha on 7 June. Fertilizer (153 kg/ha of 23-23-0) was deep banded with the same drill used for seeding to a depth of 5 to 6.5 cm. The trial was repeated in 2003 in a nearby location on the Field Station; in this year, the plot measured 60 x 40 m, and was seeded on 10 June. Seeding and fertilizer were as in 2002.

Lygus populations were manipulated by an early season insecticide treatment and by late season treatments in cages (Table 8). For the insecticide treatment, the field plot was divided into two sections. No insecticide was applied to one third of the plot area in 2002 (60 x 10m) and half of the plot area in 2003 (60 x 20m), and so these areas had the normal field density of lygus bugs without any insecticide manipulation. The remaining portions of the plot, received an application of the pyrethroid insecticide cyhalothrin-lambda (Matador®) at a rate of 83 ml product/ha. The insecticide was applied using a tractor-mounted sprayer at 200 L / ha. The trial was designed so that the early season insecticide was applied in response to the first observation of adult lygus bugs. The first observation of lygus bugs in the buckwheat plot was on 22 July in 2002 and 16 July in 2003. The insecticide was applied on 30 July in 2002 and on 28 July in 2003.

The late season treatment was initiated on 20 August in 2002 and 27 August in 2003. Netting cages (Fig. 15) were installed to enclose the apical three flowering / seeding nodes of two pollination-compatible plants, one with pin type flowers and the other with thrum type flowers. Each cage was supplied every 5-7 days with 15 blow flies, *Protophormia terrae-novae* (Rob.-Desv.) to ensure pollination. Cages were supported on stakes about 2 m high. In each year, a total of 60 cages, 30 of them for each early season insecticide treatment, were set up. In each year, three late season lygus bug density treatments, each replicated in 10 cages, were applied in each early season treatment (Table 8), so that the effects of early season and late season treatments on data from cages could be investigated in a split plot design. Lygus bug numbers were adjusted to the target number in cages in each of the five weeks of the two trials. Lygus bugs in the cages were collected from nearby fields. To approximate the natural population structure, the ratio of nymphs: adults was also adjusted each week. The approximate ratio (nymph : adult) was 3:2, 2:3, 1:3, 1:4, and 1:5 in the weeks of the 2002 trial in all treatments and close to these ratios in the 5 bugs / cage treatment in 2003 trial. In the 2 insects / cage treatment in 2003, the ratios in the successive weeks were 2:0, 1:1, 1:1, 1:1 and 0:2. *Lygus lineolaris* adults were introduced into the cages; nymphs could not be identified to species but nearly all were probably *L. lineolaris* because most lygus bugs at the collection site were this species (Part 1).

Throughout the growing season, four sets of 10 (180^{o} arc) sweeps were taken each week from each of the sprayed and unsprayed sections of the plot using a 40 cm diameter sweep net at weekly intervals in 2002. In 2003, the number of sweeps per section per week was reduced to three sets of 10. On 23 September 2002 and 2003, the plant contents of each cage were harvested by hand and placed separately in a paper bag, and then the whole plot was swathed. On 10 October 2002 and 6 October 2003 the crop was combined and the seed yield of each swath in the plot was weighed separately and the seed weight / m^2 of each treatment calculated. The weight and the number of seeds and the percentage of shriveled seeds were assessed for each cage.

Relative vulnerability of plant stages to lygus bugs

To shed more light on the relationship between the plant and the insect, a trial was designed to assess which of the plant growth stages was most vulnerable to lygus injury, and which lygus bug stage was most injurious. This trial was conducted at the University of Manitoba's Fort Garry campus in Winnipeg, and replicated in the growing seasons of 2003 and 2004.

The experimental unit of this trial was a 51 cm diameter pot, in which two buckwheat plants were grown to maturity in a cage (Fig. 16). To ensure that two pollination compatible plants were available in each pot, 2-3 buckwheat seeds were planted in 4 locations 90^{o} apart around, and ~ 5 cm in from the periphery of the pot.

Pots were seeded in 6 June 2003 and 14 June 2004. Each plot was supplied with 1.5 L of water each other on alternating days and the recommended fertilizer (23-23-0) was added before seeding as part of watering process. At the time of initial flowering, the plants were thinned to leave two plants, one of each flower type. Each unit was then caged with a 2-m-high nylon mesh cage (10 threads per cm, which retained lygus nymphs). The frame of each cage was four bamboo stakes supporting a hoop of garden hose, which supported the top of the cage. The netting of the cage was secured firmly by tying its lower end and securing it with a rubber band below the upper edge of the pot (Fig. 16). Blow flies, were maintained at a density of 15 flies per six floral nodes to ensure pollination in each cage from the time of initial flowering until the end of the trial. Three plant growth stage treatments and three insect infestation treatments were applied in all possible combinations, and replicated five times in each of the two years (Table 9). Adults of *L. lineolaris* were used for this experiment, while the lygus nymphs did were not identified to the species level, but based on species composition of lygus adults (Part 1) were assumed to be almost all *L. lineolaris*. As buckwheat continues to flower from the time of first bloom until the end of the season, the stages are referred to hereafter by the most advanced structures present: flowers and floral buds, green seed, and ripe seed. The 45 pots in the experiment were set out in a randomized complete block design on a grassy area. The cages were checked every second day to insure the numbers of blow flies were adequate and to check the presence of the designated number of lygus bugs in each cage. At the end of the designated growth stage for infestation, lygus bugs were removed from the cage, and the plants were grown in cages until maturity. From the time of early flowering until maturity, total flowers and dry flowers for the two plants in each cage were counted at weekly intervals. At the time of maturity, plants of each cage were cut at soil level, put in cloth bags, and allowed to dry. Seeds were harvested by hand, and seed weight, seed number, and number and percentage of shriveled seeds were assessed for each cage.

Commercial field trials

The insecticide and cage manipulation trials demonstrated that lygus bugs have destructive effects on buckwheat yield. Therefore, the effects of lygus bugs on buckwheat yield were studied on a larger scale in commercial fields. In commercial fields, insecticides were used to manipulate lygus bug populations early and late in the season. These trials were initiated in 2003 and 2004; however, an early frost in 2004 eliminated lygus bugs and damaged the crop so the 2004 trial was abandoned and will not be treated here. In a commercial field near Altamont, Manitoba (49° 23' 19" N, 98° 25' 15" W), buckwheat variety "Koto" was seeded on 4 June 2003 at a rate of 65 kg / ha, with 135 kg/ha of 23-23-0 fertilizer banded with seeding drills 5 to 6.5 cm deep. Sixteen plots, each measuring 20 x 30 m were measured and marked by metal stakes about 3 weeks after seeding. The lygus bug populations were manipulated by applications of the insecticide Matador® (cyhalothrin-lambda, 120 g/L) at the rate of 83 ml product/ha, using a tractor-mounted sprayer with volume of 200 L / ha. The following treatments were replicated four times in a randomized complete block design:

- An insecticide application on 28 July 2003 after the first observation of lygus bugs.

- An insecticide application on 3 September 2003. This application followed the onset of the influx of lygus adults in late August and early September.
- Two insecticide applications, one application on July 28 and the second on 3 September 2003.
- No insecticide application.

At weekly intervals from the start of plant flowering until the time of harvest, a sample of ten 180° arc sweeps was taken along the diagonal of each plot using a 40 cm diameter sweep net. Samples were kept in an insulated cooler for transportation to the laboratory, where they were placed in a freezer to kill and preserve the specimens. Adults were identified to species using the keys of Kelton (1975, 1980), Schwartz and Foottit (1992a) and Mueller et al. (2003). Nymphs were identified to the generic level.

On 21 September 2003, two 1 m^2 areas were hand harvested from each plot. The harvested samples were kept separately in cloth bags to dry, and then seeds were extracted using a stationary harvesting machine. On 24 September 2003, a 20 m^2 area was swathed from each plot using gasoline powered-scythe. The swathed areas were harvested with a Wintersteiger small-plot combine harvester 12 days later. At the time of combining, losses at the combine pick up and in chaff were assessed. Two 0.55 x 0.45 m plastic trays were put randomly on the swath, with the distance between them equal to the distance between the pick up and the chaff output of the combine. The trays were positioned so that one was in front of the pick-up and one was between the pick-up and the chaff output. The combine was driven over the trays, so that the lost seeds due to the pick up loss and the seeds lost in the chaff were separately collected on the two plastic trays. The seeds on each tray for each swath were sorted from other debris and collected in separate paper bags. All the harvested samples were allowed to dry and then were cleaned using air winnowing and sieving. The samples were then weighed using a top loading digital scale with capacity of 200 kg.

Managing lygus bugs on buckwheat with Matador® and Botanigard®

In the growing seasons of 2003 and 2004, a trial was conducted at the University of Manitoba's Fort Garry campus in Winnipeg to assess the efficacy of cyhalothrin-lambda (Matador®) against early season populations of lygus bugs, and of the mycoinsecticide *Beauveria bassiana* strain GHA (Botanigard ES®) against late season populations of lygus bugs on buckwheat.

Each year, 16 plots, each 2 x 20 m, were set up in a randomized complete block design. Pesticide treatments were either Matador® (cyhalothrin-lambda, 120 g/L) at the rate of 83 ml product/ha with volume of 200 L / ha, or the emulsifiable suspension formula of Botanigard at the rate of 500 ml product per 380 L water / ha. The sprays were applied using a back pack sprayer with a 2 m boom. Four treatments, Matador® at early season only, Botanigard® at late season only, Matador® at early season and Botanigard® at late season, and control (no application) were set up according to Table 10. A sample of ten (180°) arc sweeps was taken from each plot immediately before and one week after each application. Methods of preservation and identification of insects were the same as previously described. After the Botanigard® application, the level of infection with fungus was assessed at 3-4 day intervals by collecting lygus bugs from the plots using a sweep net or aspirator, killing them by freezing, and puting them on wet filter paper in Petri dishes sealed with parafilm at 25°C and 100% R.H. in a growth chamber. Insects were considered infected if, after a 48 h incubation, there were fungal hyphae on or around the body. Plots were harvested using a plot combine on 6 October 2003 and 2 October 2004, and the seeds were dried and weighed.

Statistical analyses

When necessary, data other than percentages were transformed using $\log_{10}X$ or $\log_{10}(X + 1)$ to reduce heteroscedasticity. The arcsine transformation was used for percentages. An alpha level of 0.05 was used for all analyses. All analyses were conducted using Systat® 10, or later version, software (SPSS 2000).

Unpaired t-tests were used to examine the difference between sprayed and control treatments of the Carman field plots. Analysis of variance (ANOVA) was performed using a split plot design for the caging trials in the early spray and control sections of the field plot at Carman. Where treatment effects of the initial analysis were significant, analysis of separation of means was performed using Tukey's test.

A randomized complete block analysis of variance was performed on data from the large cage trial at the University of Manitoba. The contrast of each insect treatment with the corresponding control was considered as an *a priori* test and was carried out using a 1-tailed t-test in which the test-wise alpha was adjusted using the Sidak multiplicative inequality to maintain the error rate for the six contrasts (two for each of three plant growth stages) at alpha = 0.05.

Analyses of variance were performed with a randomized complete block design for the commercial field trial at Altamont and the trial of Matador ® and Botanigard®

at the University of Manitoba Campus. Where the F statistic for treatments was significant, Tukey's test was used to determine the patterns of differences among means.

Results

Effects of lygus on caged flower heads

The presence of lygus bugs in cages containing flower heads resulted in obvious differences in seed yield in 2002 (Fig. 17): seeds were fewer and smaller in infested cages. In 2002, lygus bug infestation of caged heads of buckwheat late in the season reduced seed weight ($F = 65.5$; df $= 2,38$; $P < 0.001$) (Table 11). The mean weight of seeds per cage of the control (0 lygus bugs) was about 4.5 times that for 20 bugs per cage treatment and the seed weight in cages with 5 lygus bugs was intermediate. The early season insecticide application had no significant influence on seed weight ($F = 0.1$, df $= 1,38$) (Table 11); nor did lygus bug treatment in the cages interact significantly with the insecticide application early in the season ($F = 0.8$, df $= 2, 54$).

Lygus bugs in cages in 2002 also reduced the number of seeds produced ($F = 11.9$, df $= 2,38$, $P < 0.001$) (Table 11). This effect was mostly a result of differences in seed numbers in cages with and without lygus bugs; there were no significant differences in seed number between the two levels of lygus infestation. Early season insecticide application had no significant effect on the number of seeds per cage ($F = 2.7$, df $= 1,38$) (Table 11). Also insecticide treatment did not influence the response to late season lygus bug numbers ($F = 0.7$, df $= 2, 54$) (Table 11).

The percentage of shriveled seeds per cage increased with the number of lygus bugs in cages (F = 105.6, df = 2, 38, P<0.001) (Table 11). Unlike for seed weight and number, the early season treatment significantly influenced the percentage of shriveled seeds (F = 9.2, df = 1,38, P<0.01), reducing the shrivelling in the cages in the sprayed portion of the plot (Table 11). The interaction of early and late treatments was also significant (F = 2.9; df = 2,54; P<0.01). In the absence of the insecticide treatment, 29 ± 1, 68 ± 4 and 75 ± 4% of seeds were shriveled in the 0, 5 and 20 bugs per cage treatments respectively. In the presence of insecticides, the corresponding values were 27 ± 2, 50 ± 5 and 71 ± 2%. Thus it appeared that at intermediate levels of the cage treatment the effect of the insecticide treatment on seed shriveling was most evident.

In 2003, lygus bug numbers in cages again reduced seed weight (F = 11.8; df = 2, 38; P < 0.001), particularly for 5 bugs / cage (Table 11). Early season insecticide application had no significant influence on seed weight per cage (F = 1.6 df = 1, 38) (Table 11), nor was seed weight significantly influenced by the interaction of early season insecticide application and lygus density in cages (F = 2.2; df = 2, 54). In 2003, the number of seeds produced was not affected by lygus bugs (F = 3; df = 2,38) (Table 11), early season insecticide application (F = 1.6; df = 1,38) or their interaction (F = 0.07; df = 2, 54). The percentage of shriveled seeds was higher in the five than for two or no lygus bugs in cages in 2003 (F = 6.6; df = 2, 38; P<0.01) (Table 11). The interaction of lygus numbers in cages and the early season insecticide application was not significant (F = 0.7; df = 2, 54). Seed weight, seed number and the percentage of shriveled seeds in 2003 were not significantly affected by the early-season insecticide application (Table 11).

Relative vulnerability of plant stages to lygus bugs

The duration of the three growth stages of buckwheat were different in their durations; while the flowers and flower bud stage lasted 12-14 days, the green seed stage lasted 21-28 days, and ripe seed stage lasted 24-25 days. In 2003, six cages were lost due to weather conditions.

The results of the trials in 2003 and 2004 showed that the basic pattern of responses in each year was the same and the growth pattern of the plants in the cages was similar to and well synchronized with that observed in the field. Statistical analysis showed that results from all yield parameters were significantly different between the two years, however the interaction of year and treatment showed no was not significant differences among all for any of the yield parameters tested. Based on the similar responses to treatment in the two years, the results of the 2003 and 2004 experiments were pooled for analysis which was performed as a randomized complete block design with 10 blocks, five from each year.

Artificial infestation by lygus bugs negatively affected all buckwheat yield parameters; more so at the flower stage than at the other two stages and more for nymphs than adults, and interactions between plant stage and lygus bug stage were detected. Seed weight per cage was significantly affected by the insect stage (F = 12.1; df = 2,60; P<0.01). The overall effects of the infested plant stage on seed weight per cage were significant (F = 3.8; df = 2,60; P<0.05). Nymphal infestation at the flowering stage reduced the weight of seed from caged buckwheat plants to about one quarter compared to the control ($t = 2.3$; df = 1,60; $P<0.05$), while adult infestation of the flowering stage did not affect seed weight significantly ($t = 1.2$; df = 1,60) (Table 12). The infestation of green seed or ripe seed stages by lygus bugs had no significant impact on the seed weight of caged buckwheat plants (Tables 13 & 14). The infestation treatment of the flower stage was responsible for over 91% of the total treatment sums of squares of seed weight per cage (Table 12); nymphal infestation relative to controls at the flowering stage accounted for almost 82% of the total treatment sums of squares.

Seed number per cage was significantly affected by the insect stage ($F = 6.3$; df = 2,60; $P<0.01$). The overall effects of the infested plant stage on seed number per cage were not significant ($F = 1.9$; df = 2,60) but the interaction of plant stage and lygus bug treatment was significant ($F = 5.8$; df = 4,60; $P<0.01$). Infestation treatments during the flower stage significantly affected number of seeds ($F = 4.2$; df = 2,60; $P<0.03$); the number of seeds in cages with nymphs was about a third of those in the control ($t = 5.5$; df = 1,60; $P<0.05$) (Table 12). However, adult infestation at the flowering stage did not affect the number of seeds ($t = 1$; df = 1,60). Infestation by lygus bugs at either green seed or ripe seed stages had no significant effect on the number of seeds per cage (Tables 13 & 14). The infestation of the flower stage was responsible for 97% of the total treatment sums of squares for seed number per cage (Table 12), and nymphal infestation compared to the controls at the flowering stage accounted for 82% of the total treatment sum of squares.

The percentage of shriveled seed in a cage was affected significantly by lygus bug infestation ($F = 7.6$; df = 2,60; $P<0.01$). Plant stage did not significantly affect the percentage of shriveled seeds ($F = 1.4$; df = 2,60); and the interaction of plant stage and lygus bug treatment was not significant ($F = 2.4$; df = 4,60). Infestation treatments during the flower stage significantly affected the percentage of shriveled seeds ($F = 6.8$; df = 2,60; $P<0.01$). Nymphal infestation at the flower stage significantly increased the percentage of shriveled seeds comparing to control ($t = 3.4$; df = 1,60; $P<0.05$) (Table 12), but adult infestation of the flowering stage had no effect ($t = 0.7$; df = 1,60) (Table 12). Infestation treatments at the green seed stage affected percentage of shriveled seeds ($F = 4.1$; df = 2,60; $P<0.05$) (Table 13). Infestations at the ripe seed stage did not affect the percentage of shriveled seeds. The infestations at the flower and the green seed stages were responsible for almost 55 and 43%, respectively, of the total treatment sum of squares Table 12 & 13).

The number of flowers in each cage each week was summed over the weeks of the experiment. These cumulative total numbers of flowers were not significantly affected by lygus bug infestation ($F = 1.7$; df = 2,60), neither was there a significant effect of plant stage ($F = 2.4$; df = 2,60) or the interaction of the two ($F = 1.8$; df = 4,60). Infestation during the flower stage affected the number of flowers per cage significantly ($F = 5.4$; df = 2,60; $P<0.01$). Plants infested at the flowering stage with nymphs had significantly fewer flowers than those of the control ($t = 2.3$; df = 1,60; $P<0.05$) (Table 12). The infestation of lygus bugs on green seed and ripe seed stages of caged buckwheat plants had no significant effect on the number of flowers per cage ($F = 0.02$ and 0.06 respectively; df = 2,60) (Tables 13 & 14). The infestation of the flower stage was responsible for virtually the entire overall treatment sum of squares for number of flowers per cage, and 91 % of the treatment sum of square was attributable to the difference between nymphs and control at this stage (Table 12).

The number of dry flowers in a cage each week was summed over the experimental period and the total expressed as a percentage of the cumulative total number of flowers. This percentage was significantly affected by lygus bug infestations (F = 19.4; df = 2,60; P<0.01), but the effect of the infested plant stage on the percentage of dry flowers was not significant (F = 0.22; df = 2,60) (Table 12 - 14). The interaction between plant stage and lygus bug infestation significantly affected the overall percentage of dry flowers (F = 3.7; df = 4,60, P<0.01). Infestation by nymphs during the flower stage significantly affected the percentage of dry flowers (F = 19.1; df = 2,60; P<0.01) by increasing the percentage of dry flowers compared to the control, although adult infestation of the flowering stage had no significant effect (Table 12). The percentage of dry flowers was also significantly affected by infestation at the green seed stage (F = 5.5; df = 2,60; P<0.01) (Table 13). Nymphal and adult infestation of the green seed stage significantly affected the percentage of dry flowers per cage compared to the control (Table 13). The lygus bug treatment at the ripe seed stage also significantly affected the percentage of dry flowers (F = 12.1; df = 2,60; P<0.01). The infestation of lygus nymphs at the ripe seed stage of caged buckwheat plants significantly increased the percentage of dry flowers comparing to the control (t = 2.3; df = 1,60; P<0.05) (Table 14). The infestation of the flower stage was responsible for over 71% of the overall sum of squares and 37 % of the treatment sum of squares was attributable to differences between the control and nymphal infestation treatment at the flowering stage (Table 12).

Effects of insecticide application on lygus numbers

In the field plot trial at Carman in 2002, adult lygus bugs first appeared in the field plot on 22 July (Fig. 18a). They reached an average of 9.3 and 8.8 insects per 10 sweeps in the week before and the day of the insecticide application, respectively. For two weeks following the insecticide application, adult catches in the sprayed area were close to zero, but thereafter the numbers of lygus adults were similar in both sprayed and unsprayed sections of the field plot. The numbers of adults increased in September, and reached a maximum of 86.75 / 10 sweeps in the sprayed section on 16 September (Fig. 18a). The nymphs first appeared at the end of July, and continued to inhabit the unsprayed section of the field plot until the end of the season. In the sprayed section of the field plot, nymphs first appeared on 26 August (Fig. 18b). The total number of nymphs in the unsprayed section was more than twice that in the sprayed section of the field plot although the total numbers of adults were similar in both sections (Table 15).

In 2003, adult lygus bugs appeared in the field plot on 16 July (Fig. 19a), and in the three samples before insecticide application averaged 2, 7.75 and 4.25 / 10 sweeps. Catches of lygus bugs in the week after the insecticide application were generally close to zero in the sprayed section of the plot, and for the remainder of the season numbers of adults were similar in both sections (Fig. 19a). The low catches during the first week of September (Fig. 19a & b) were due to heavy rain (30 mm during the week of sampling). In 2003 the nymphs first appeared on 23 July, and continued until the end of the season. In the sprayed section of the field plot, nymphs reappeared in 11 August (Fig. 19b). The total number of nymphs in the unsprayed section was over 1.75 times that in the sprayed section of the plot, but total numbers of adults were similar in both sections of the plot (Table 15).

For the commercial field trial in 2003, the mean numbers of lygus adults and nymphs in sweep net samples are presented in Figures 20a & b. Lygus adults appeared on 16 July (Fig. 20a) and reached an average of 6.56 / 10 sweeps on 28 July, the day of the early insecticide application. In the following week, adult numbers were lower in all treated plots than untreated ones, but these differences did not persist. In the third week of August, adult numbers reached a sudden peak, with peak catches much greater than those of nymphs in the corresponding plots (Fig. 20a, b). Adult numbers continued to increase in the early spray and the untreated check plots until the end of the season, but they dropped near to zero in the late spray and two spray plots after the late season insecticide application on 3 September (Fig. 20a). The low catches in the week of 1 September were due to heavy rain reducing sampling efficiency. Nymphs appeared in very low numbers by the third week of July, and during August their numbers were greatly affected by the early spray application in the early spray and two spray treatments (Fig 20b). The total number of nymphs caught during the season was greatly affected by treatments with an early spray, but little by the later spray (Table 16).

The influences of insecticidal control of lygus bugs on yield

In the field plot trial at Carman in both 2002 and 2003, the yield (Table 17) in the unsprayed section of the buckwheat field plot was lower than in the sprayed part of the plot (2002: $t = 38$; df = 3; $P < 0.01$; 2003: $t = 6.8$; df = 8; $P < 0.05$).

In the commercial field trial at Altamont in 2003, the application of insecticide increased yields in comparison with the untreated check (Table 18) for both hand ($F = 7.5$; df = 3,9; $P<0.01$) and combine harvested plots ($F = 6.5$; df = 3,9; $P<0.05$). In both cases, the trends were similar with plots receiving two sprays yielding most, an early spray next, a late spray next, and no spray yielding least (Table 18).

Overall, estimates from hand harvesting were about 2.3 times those from a combine harvester. The percentage of yield lost at the combine harvester pickup was lower with an early insecticide application ($F = 4.2$; df = 3,9; $P <0.05$) (Table 19). No significant effect of the insecticide treatments on the loss of seed in chaff was detected ($F = 0.4$; df = 3,9) (Table 19).

Managing lygus bugs on buckwheat with Matador® and Botanigard®

In 2003 and 2004, the numbers of lygus bug adult and nymphs were similar in treatments in the week before Matador® application (Fig. 21, 22). In 2003, the lygus bug numbers before the Matador® treatments were relatively high with almost equal proportions of adults and nymphs (Fig. 21); numbers were lower in 2004 and most were adults (Fig. 22). Compared to the untreated plots, the Matador® application reduced the numbers of lygus bugs in the treated plots by about 90 % and 100 % in 2003 and 2004 respectively. In the week before the Botanigard® application, the numbers of lygus bugs were again similar among the treatments (Fig. 21, 22), and the population was primarily adult. The number of lygus bug adults and nymphs was reduced in all treatments after the Botanigard® application. This reduction was not attributable to mortality from the Botanigard® (Fig. 21, 22). However, the Botanigard® applications increased the level of fungal infection of lygus bugs in 2003 ($F = 54.5$; df = 3,57; $P<0.001$) (Fig. 23a), and 2004 ($F = 39.7$; df = 3,57; $P<0.001$) (Fig. 23b). Fungal infection was about 80% in Botanigard-treated plots in the first week after application, and high, but dwindling, infection rates persisted for the two weeks period following the mycoinsecticide application (Fig. 23a & b).

In 2003, the insecticide treatments increased the yield of buckwheat seed ($F = 12.1$; df = 3,9; $P<0.01$) but no significant differences were detected among insecticide treatments (Table 20). In 2004, the treatments also increased yield ($F = 3.4$; df = 3,9; $P<0.05$), but the only significant difference that was detected was between the combined Matador® and Botanigard® treatment and the check (Table 20).

Discussion

During the cage study of flower heads of buckwheat plants, numbers of lygus bugs confined in cages were chosen to produce effects on plants, and showed that 20 bugs per cage reduced the seed yield by reducing the number of seeds and through shriveling of some of seed. The five bugs per cage diminished seed yield in both years, most consistently through shriveling seed. The results of these caging trials showed that lygus bugs in cages have at least two effects. The first one is to reduce the seed numbers per cage by feeding on the reproductive structures of the plant, and causing abortion of these structures in a manner similar to that observed for other host plants (Hughes 1943; Khattat and Stewart 1975; Tugwell et al.1976; Gupta et al. 1980, Schaefers 1980, Stewart and Khattat 1980; Boivin and Stewart 1982; Weires et al.1985; Michaud et al. 1989; Butts and Lamb 1990b, 1991a; Mailloux and Bostanian 1988; Handley and Pollard 1993a; Turnock et al. 1995; Easterbrook 2000), which would result in the decrease of the seed numbers. The second effect is the shriveling or shrinking of a large proportion of seeds in cages infested with lygus bugs.

Although these results show that lygus bugs can have impacts on buckwheat plants and can influence yield parameters, the trial timing, started late in August, partially missed the early damage of lygus bugs at the beginning of flowering.

In the large cages containing two plants, the flowering stage was the most vulnerable stage of buckwheat plant, and the nymphal stage of lygus bugs was much more injurious than the adults. This result was obtained although the duration of the flowering stage of buckwheat was 12-14 days, much less than the green seed stage or the ripe seed stage. The infestation of lygus nymphs at the flowering stage reduced the seed yield, the number of seeds and the number of flowers by 74%, 68% and 32%, respectively, relative to the uninfested check, and increased the percentage of shriveled seeds and the percentage of dry flowers by 1.6 and 3.5 times, respectively. It is evident that not all the decrease in seed weight was the result of direct feeding on the seeds. The early infestation of lygus, especially nymphs, seems to harm the flowers and floral buds of buckwheat, causing a high proportion of dry flowers. As a result, the number of flowers available for seed setting, and consequently, the number of seeds decreased. With lower number of flowers and seeds, the yield was reduced. From Table 12, one can estimate that infestation by nymphs during the flower stage was responsible for a 67% reduction in seed number, and that 31% of this reduction is attributable to reduced number of flowers (bud abortion), a further 26% is attributable to flower abortion (dry flowers), and the remainder (10%) is presumably abortion of developing seeds. It appears that nymphs and adults cause production of light and shriveled seeds. The difference between the 67% reduction in seed number and the 74% reduction in seed weight is presumably the result of the increase in seed shriveling. Even though the flower stage is shorter than the two other stages, it is far more vulnerable to infestation with lygus bugs, particularly the nymphs. The percentage of dry flowers caused by feeding nymphs continues to increase in green seed and ripe seed, but this probably makes little difference to yield as earlier seed set probably contributes most to yield. The major influences on seed shriveling and yield were not at the ripe seed stage, the stage about which producers have been most worried because of high late season populations of adults in the field.

The vulnerability of the flower stage and the damage caused by nymphs and adults lygus bugs to buckwheat plants are consistent with observations on other crops. Bud, flower and seed abortion, seed collapse and fruit malformation or shriveling are well known responses of plants to lygus feeding. Lygus bugs can cause one or more of these types of damage to many host plants (Young 1986). Infestation of buds, flowers and pods of canola causes them to abscise, the seed to collapse and there to be a reduction in weight of healthy seeds per pod (Butts and Lamb 1990b; Turnock et al. 1995). Given that nymphs reach their maximum abundance by the late flower stage and pod development stage of canola (Leferink and Gerber 1997), it is likely that nymphs cause most of the damage at this stage. Lygus bugs can cause alfalfa blossom drop, seed shriveling and seed weight reduction so that seeds are lost during seed cleaning (Shull et al. 1934). Immature alfalfa seeds are damaged only by large nymphs and adults (Gupta et al. 1980). Nymphs feeding on caged soybean buds and blossoms reduced the number of pods per node, the number of seeds per pod and the weight per seed, while adult feeding causes deleterious effects only on fruiting structures (Broersma and Luckmann 1970). These results are in accordance with my finding of the effect of lygus nymphs on buckwheat plants.

In open field trials, with plant bug densities manipulated by insecticides, similar effects of lygus bugs on buckwheat were revealed. For example, in the same plots used for cage tests, Matador® treatments reduced bug densities and the increased yield was in accord with that in the cage study with whole plants. The early season insecticide treatment with Matador® resulted in lower numbers of lygus nymphs in the treated section of the field plot compared to the untreated section, especially during August. As a result of this early season application, yield in treated plots was 12 to 78 % higher than in corresponding untreated ones in all trials with an early season Matador® application (Table 21).

The flower stage of buckwheat plants in the field coincides with the peak of nymphal populations from late July to the end of August. This synchronization of the most vulnerable stage of the plant with the most injurious stage of the insect resulted in a significant decrease in yield in cage and insecticide manipulation studies. Matador® applied in late July is likely to kill newly hatched nymphs. As a result the populations of nymphs were reduced effectively and their effects on yield were diminished. Another effect on the yield, but relatively less damaging, is shriveling of seed. This effect results from feeding of both adult and nymph lygus bugs, and augments the previous effects in contributing to lost buckwheat yield.

Despite its efficiency in reducing the lygus adult populations, late season treatment of Matador® showed no effect on the machine-harvested yield compared to the untreated check, but using caged plants in the small cage trial at Carman in 2002 and 2003 demonstrated that, in addition to the early season losses, the presence of lygus bugs on buckwheat in late August and September reduced seed weight and seed number and increased the percentage of malformed seeds. Thus, although management of nymphs at flower stage is most important, large populations of late season lygus bugs have the potential to reduce yield and further investigation into how to manage them is needed.

It was difficult to relate cage results to field conditions. In the buckwheat plot at Carman in 2002 and 2003 there were fewer lygus bug adults and nymphs in the sprayed section than in the untreated section, and yield from swath in the sprayed section was higher, but this effect on swath yield was not evident for the seed yield in cages. Several hypotheses might explain the different responses of the cage yield and machinery harvested yield to the early treatment. Firstly, plants in the zero bugs per cage treatment were protected from the naturally-occurring late lygus bug infestation and might compensate for effects of early season treatment and the 20 bugs per cage treatment could overwhelm the plant compensatory response and might cause "extra damage". The 5 bugs per cage might be considered the highest density of insects likely in field conditions and probably allowed no or very little compensation for effects of lygus bugs earlier in the season. Thus, the late season treatment in most of the cage treatments might obscure any effects of the early treatment on cage yield. The second hypothesis is that the early insecticide application effects might last far into the late season and be continued in cages by the imposition of infestation treatments. This possibility is supported by the data which indicate that lygus adults and nymphs in the sprayed section of the plot were considerably lower than the unsprayed section until about mid September, a time which the late season caging treatment had been in place for several weeks. A third hypothesis is that at least some portion of the shriveled seeds might be lost from yield during the machine harvesting and seed sieving, while this proportion might be collected from cages which were harvested by hand. A fourth hypothesis is that cages only enclosed the three apical floral nodes of two compatible buckwheat plants, and the yields and responses of this portion of the plant might differ from those of the whole plant which was harvested by swathing and combining.

Based on the other studies, it seems improbable the persistence of insecticide effects as suggested in the second hypothesis are important: both the field study at Altamont and the large cage study show that yield is most influenced by infestation at the flowering stage.

In the caged potted plants study, late season infestations of the whole plant did not influence hand harvested seed yield. So, I conclude that a major contributor to the disparity in yield estimates was probably pick up loss by the combine. It is also possible that the apical portions of plants, particularly when caged, respond differently to infestation than do whole buckwheat plants.

The early insecticide application of Matador® effectively reduced the nymph populations at the flowering stage and, over five trials where this occurred, resulted in yield gains of 12-78 % increase in the yield (Table 21). I attempted to derive an economic injury level (EIL) for lygus bugs on buckwheat from the available data, but without reaching a useful result. When lygus-nymph-weeks are plotted against the percentage of loss in yield in the untreated check compared to the early insecticide treatment (Fig. 24a), no consistent relationship was detected. While one nymph-week resulted in almost 70 % decrease in yield in one trial, 55 nymph weeks caused about 58 % loss in the yield in another (Fig. 24a). Sweep net sampling is an inefficient method of assessing numbers of the younger instar nymphs (Saugstad et al. 1967; Snodgrass 1993). Thus, if sweep net sampling is used, it must be applied to adults in July in order that control of nymphs can occur in a timely way. However, although there was a tendency for yield loss to increase with adult catches, the relationship was not significant. Furthermore even the lowest densities of adults were associated with unacceptably high yield loss (Fig. 24b). Three lygus adults per 10 sweeps in July resulted in about 70% loss in yield in one trial and over 11 adults caused an 89% loss but 4 adults were associated with only 56% loss (Fig. 24b).

Buckwheat is highly vulnerable to lygus bug infestation and even very low populations of nymphs or early season adults are associated with significant damage to the crop. Because of this vulnerability of the buckwheat plant to the infestation of lygus bugs, it is not reasonable to await development of an economic injury level before controlling lygus bug populations. These observations, and the inconsistency of the relationship between lygus bug adults and/or nymphs, lead to a recommendation to sample the buckwheat crop by sweep net at the time of initiation of floral buds. The presence of lygus bug nymphs or adults in the samples should trigger use of an insect control measure.

The time of harvest of buckwheat is unpredictable, as it is related to the time of the first killing frost. Every day of growth in fall increases yield, but following the frost, unharvested buckwheat rapidly deteriorates in the field. Thus, the pre-harvest intervals of conventional insecticide applications directed at controlling late season injury are problematic. The commercial formulation of the GHA strain of the insect pathogen fungus *B. bassiana*, BotaniGard® has a 0 day preharvest interval (Environmental Protection Agency 2003) and could provide safe protection from late season injury. The late season treatment of Botanigard® had variable effects on seed yield but caused no reduction of lygus bug numbers even though there was increased infection with fungus in the treated plots. It is possible that the infected lygus bugs did not feed, and so their presence on the crop did not result in damage. In many cases, *B. bassiana* applications reduce feeding (Soeglaff et al. 1997; Kouassi et al. 2003) and this is typical of fungal infection. However, in one study (Noma and Strickler 2000), *L. hesperus* infected with *B. bassiana* had elevated feeding rates. The difference in the effects of Botanigard® on yields in 2003 and 2004 might be related to the weather conditions. In 2003, the season was warmer with no early frost and there was precipitation around the time of application which would favour fungal growth. In 2004 the crop suffered from an early frost in late July and colder temperatures occurred late in the season which might have also affected fungus propagation. Given the special humidity requirements of the fungus, it could be more appropriate to search for local strains of the fungus and propagate them for screening against plant bugs, and possibly other insect pests. However, local development of strains will require expensive registration procedures.

Due to their large numbers, lygus bug populations late in the growing season were the greatest concern for growers, and the reason for conducting this study. However, suppression of these populations by Matador® did not result in yield gain. An application of Botanigard® at the same time produced a yield gain in one year and no effect in the other. Late in the growing season, the lygus bug population is mostly adults, which are quite mobile (Gerber and Wise 1995), thus they can re-colonize the crop after an insecticide application. In the case of Botanigard®, the fungus may affect the insects' feeding but does not affect their numbers. The benefits of late season control of lygus bugs seem equivocal in this study, and would always be highly dependent on the time elapsing between control and the first killing frost. I conclude that there is a strong case for applying an insecticide when lygus bugs are detected at the time of floral bud initiation in late July or early August. Late season application of insecticide may occasionally confer yield benefits, but the majority of evidence from my research indicates benefits may be small and relatively rare.

Table 8: Scheme of treatments for assessing damage to buckwheat seed by of lygus bugs in a split plot design at Carman in 2002 and 2003.

Year	Insecticidal study (Early Season)	Enclosure study (Late season using cages enclosing two flower heads)
2002	No insecticide application used	No lygus bugs
		5 lygus per cage
		20 lygus per cage
	Insecticide application in late July	No lygus bugs
		5 lygus per cage
		20 lygus per cage
2003	No insecticide application used	No lygus bugs
		2 lygus per cage
		5 lygus per cage
	Insecticide application in late July	No lygus bugs
		2 lygus per cage
		5 lygus per cage

Table 9: Treatments used to assess vulnerability of buckwheat plant stages to infestation of lygus bugs at the University of Manitoba Campus in the growing seasons of 2003 and 2004.

		Plant stage		
		Flowers & floral buds	Green seeds	Ripe seeds
Duration of stage (days)	2003	12	21	24
	2004	14	28	25
Treatment				
Nymph		5 / cage	0 / cage	0 / cage
		0 / cage	5 / cage	0 / cage
		0 / cage	0 / cage	5 / cage
Adult		5 / cage	0 / cage	0 / cage
		0 / cage	5 / cage	0 / cage
		0 / cage	0 / cage	5 / cage
Control		0 / cage	0 / cage	0 / cage
		0 / cage	0 / cage	0 / cage
		0 / cage	0 / cage	0 / cage

Table 10: Insecticide treatments and dates of applications of Matador® and Botanigard® at the University of Manitoba campus in the growing seasons of 2003 and 2004

Treatment	Material sprayed	Date of application	
		2003	2004
Early spray	Matador®	31 July	12 August
Late spray	Botanigard®	5 September	16 September
Two sprays	Matador® then Botanigard®	31 July & 5 September	12 August & 16 September
Control	None	---	---

Table 11: Seed production (Means ± SEM per cage) by buckwheat caged with lygus bugs in plot areas that received early-season insecticide application or no insecticide at Carman, MB.

Year	Treatment	Seed weight (g)	Seed number	% shriveled seed
	Early			
	No insecticide	1.7 ± 0.2	117 ± 9	57 ± 4
	Insecticide	1.7 ± 0.2	100 ± 8	50 ± 4
2002	**Late**			
	0 bugs	3.0 ± 0.2[a]	142 ± 9[a]	28 ± 1[a]
	5 bugs	1.0 ± 0.1[b]	97 ± 10[b]	59 ± 4[b]
	20 bugs	0.7 ± 0.1[c]	86 ± 10[b]	73 ± 2[c]
	Early			
	No insecticide	2.3 ± 0.2	125 ± 7	56 ± 3
	Insecticide	2.5 ± 0.1	129 ± 7	48 ± 2
2003	**Late**			
	0 bugs	2.8 ± 0.2 [a]	128 ± 7 [a]	47 ± 2 [a]
	2 bugs	2.6 ± 0.2 [a]	140 ± 11 [a]	47 ± 3 [a]
	5 bugs	1.8 ± 0.2 [b]	113 ± 7 [a]	61 ± 4 [b]

Within columns of the same year, late treatment means followed by the same letter do not differ significantly. Tukey's test (α = 0.05) was used to compare all means within the late treatment.

Table 12: Means (± SEM) for yield parameters for buckwheat plants infested artificially at the flower stage by lygus bug nymphs and adults: pooled results of the 2003 and 2004 trials.

Values per cage	Control	Nymphs	Adults	% of total treatment sums of squares attributable to infestation at flower stage[1]
Seed yield (g) (average seed weight (g))	34 ± 4 (0.0249)	9 ± 4 * (0.0203)	25 ± 6 (0.0226)	91
Number of seeds	1364 ± 189	444 ± 156 *	1107 ± 218	97
Shriveled seed (%)	33 ± 4	55 ± 6 *	39 ± 3	55
Number of flowers	1438 ± 108	989 ± 135 *	1324 ± 150	100
Dry flowers (%)	12 ± 3	43 ± 10 *	20 ± 7	71

Within rows, means followed by (*) differ significantly from control. One-tailed t test (testwise α = 0.0085) was used to test for significance between control and different treatments using the overall analysis error MS.

[1] (Sum of squares for infestation treatment in flower stage / (sum of squares for infestation over all stages + sum of squares for infestation treatment x plant stage)) x100

Table 13: Means (± SEM) for yield parameters for buckwheat plants infested artificially at the green seed stage by lygus bug nymphs and adults: pooled results of the 2003 and 2004 trials.

Values per cage	Control	Nymphs	Adults	% of total sums of squares attributable to infestation at green seed stage[1]
Seed yield (g) (average seed weight (g))	34 ± 8 (0.0341)	23 ± 6 (0.0234)	26 ± 7 (0.0246)	6
Number of seeds	1167 ± 240	981 ± 233	1055 ± 271	2
Shriveled seed (%)	28 ± 4	45 ± 4 *	42 ± 6 *	43
Number of flowers	1452 ± 184	1399 ± 204	1459 ± 209	0
Dry flowers (%)	16 ± 6	34 ± 7 *	28 ± 8 *	21

Within rows, means followed by (*) differ significantly from control. One-tailed t test (testwise α = 0.0085) was used to test for significance between control and different treatments using the overall analysis error MS.

[1] (Sum of squares for infestation treatment in green seed stage / (sum of squares for infestation over all stages + sum of squares for infestation treatment x plant stage)) x100

Table 14: Means (± SEM) for yield parameters for buckwheat plants infested artificially at the ripe seed stage by lygus bug nymphs and adults: pooled results of the 2003 and 2004 trials.

Values per cage	Control	Nymphs	Adults	% of total sums of squares attributable to infestation at ripe seed stage[1]
Seed yield (g) (average seed weight (g))	25 ± 4 (0.0251)	26 ± 5 (0.0243)	27 ± 5 (0.0260)	0
Number of seeds	997 ± 143	1069 ± 172	1039 ± 155	0
Shriveled seed (%)	40 ± 6	42 ± 5	37 ± 5	4
Number of flowers	1366 ± 76	1404 ± 79	1409 ± 119	1
Dry flowers (%)	18 ± 6	30 ± 7 *	25 ± 6	11

Within rows, means followed by (*) is differ significantly from control. One-tailed t test (testwise α = 0.0085) was used to test for significant between control and different treatments using the overall analysis error MS.

[1] (Sum of squares for infestation treatment in ripe seed stage / (sum of squares for infestation over all stages + sum of squares for infestation treatment x plant atage)) x100

Table 15: Effect of insecticide treatment on total numbers of adults and nymphs of lygus bugs / 10 sweeps in a buckwheat field plot at Carman, MB in 2002 and 2003.

	2002		2003	
	Unsprayed	Sprayed	Unsprayed	Sprayed
Total number of lygus adults	162.8	141.5	183.7	187.0
Effect of treatment (%) (100 x sprayed / unsprayed)	87		102	
Total number of lygus nymphs	107.3	46.3	63.7	36.3
Effect of treatment (%) (100 x sprayed / unsprayed)	43		57	

Table 16: Average total numbers of nymphs and adults per 10 sweeps in response to four insecticide treatments of buckwheat at Altamont, MB 2003.

	Two sprays	Early spray	Late spray	No spray
Total number of lygus nymphs	5.3	10.0	20.0	24.0
Nymphs as % of nymphs in no spray	21.9	41.7	83.3	100.0
Total number of lygus adults	41.0	89.5	73.5	126.3
Adults as % of adults in no spray	32.5	70.9	58.2	100.0

Table 17: Mean (± SEM) yields from machine harvesting in relation to early season insecticide manipulations of lygus bugs in buckwheat at Carman, MB in 2002 and 2003

Early treatment	Yield (g / m^2)	
	2002	2003
Insecticide	65 ± 2	111 ± 5
No insecticide	48 ± 2	86 ± 8

Table 18: Means (± SEM) of yields from hand and machine harvesting in relation to Matador® insecticide applications in buckwheat at Altamont, MB in 2003.

Treatment	Yield (g / m^2)	
	Hand harvested	Machine harvested
Early and late spray	214 ± 17 [a]	91 ± 1 [a]
Early spray	181 ± 17 [a]	84 ± 15 [a]
Late spray	168 ± 10 [a]	66 ± 6 [ab]
Untreated check	106 ± 12 [b]	47 ± 7 [b]

Within columns, means followed by the same letter do not differ significantly based on Tukey's test ($\alpha = 0.05$).

Table 19: Means (± SEM) percentages of pick up loss and loss in chaff for buckwheat seeds harvested by machine in relation to Matador® insecticide applications at Altamont, MB in 2003.

Treatment	Seed weight lost during harvest (%)	
	Pick up loss as % of seed in swath (w/w)	Loss in chaff as % of seed entering combine (w/w)
Early and late spray	13 ± 3 [a]	24 ± 10 [a]
Early spray	12 ± 2 [a]	21 ± 2 [a]
Late spray	22 ± 4 [b]	28 ± 6 [a]
Untreated check	28 ± 4 [b]	30 ± 8 [a]

Within columns, means followed by the same letter do not differ significantly based on Tukey's test ($\alpha = 0.05$).

Table 20: Mean (± SEM) seed yield of buckwheat in relation to insecticide treatments at the University of Manitoba's Fort Garry Campus in 2003 and 2004.

Treatment	Yield (g / m^2)	
	2003	2004
Matador® and BotaniGard®	189 ± 6 [a]	39 ± 8 [a]
Matador® early only	181 ± 2 [a]	30 ± 2 [ab]
BotaniGard® late only	176 ± 2 [a]	23 ± 2 [b]
Untreated check	161 ± 4 [b]	20 ± 2 [b]

Within columns, means followed by the same letter do not differ significantly based on Tukey's test (α = 0.05).

Table 21: Effect of an early-season application of Matador® on seed yield in five different trials in Manitoba over three years

Location	Year	Yield (g / m^2)		Percentage yield gain from spray
		Matador in July	Untreated	
Carman	2002	65 ± 1.6	48±2.3	35
	2003	111 ± 4.7	86±8.3	29
Altamont	2003	84 ± 15.1	47±6.8	78
Winnipeg	2003	181 ± 1.9	161±4	12
	2004	30 ± 2	20±1.6	50

Fig. 15: Net cage used to enclose two buckwheat flowering/seeding heads in field plot at the Carman Research Station, Manitoba

Fig. 16: Net cage used to enclose two buckwheat plants to assess impact of lygus bugs on yield at different plant growth stages

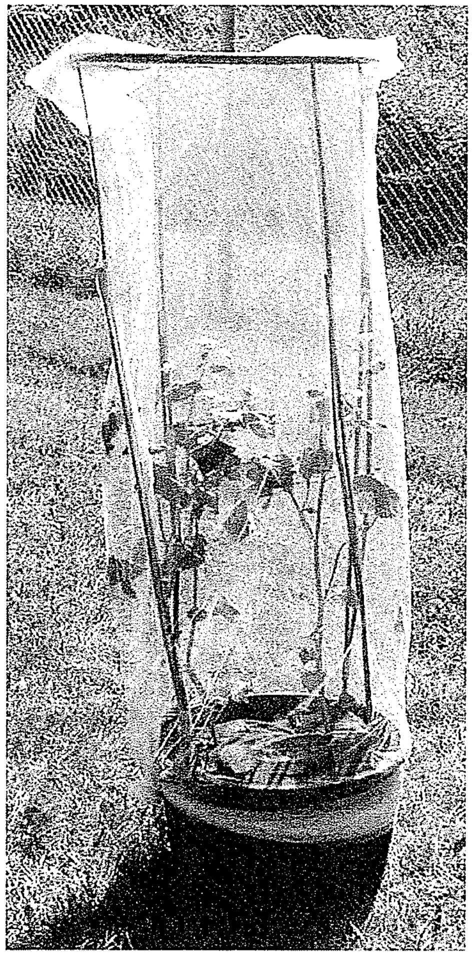


Fig. 17: Seed yield from cages containing 0, 5 or 20 lygus bugs on buckwheat at Carman, MB late in the season of 2002.

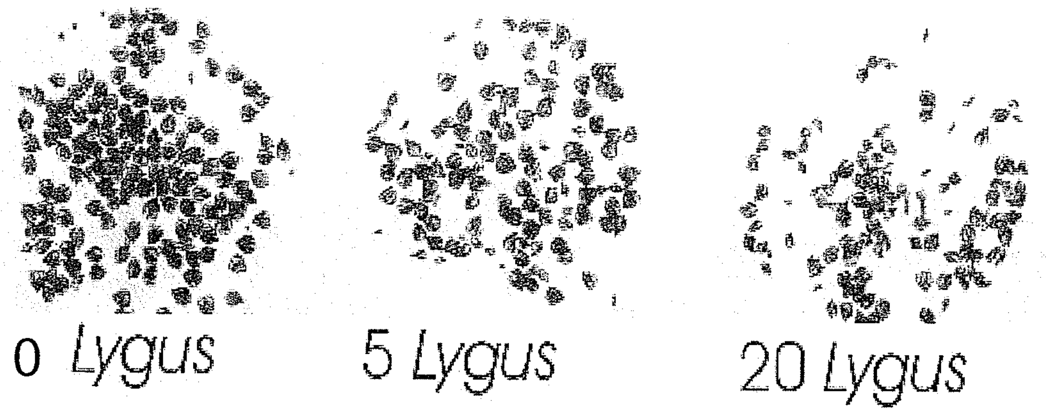
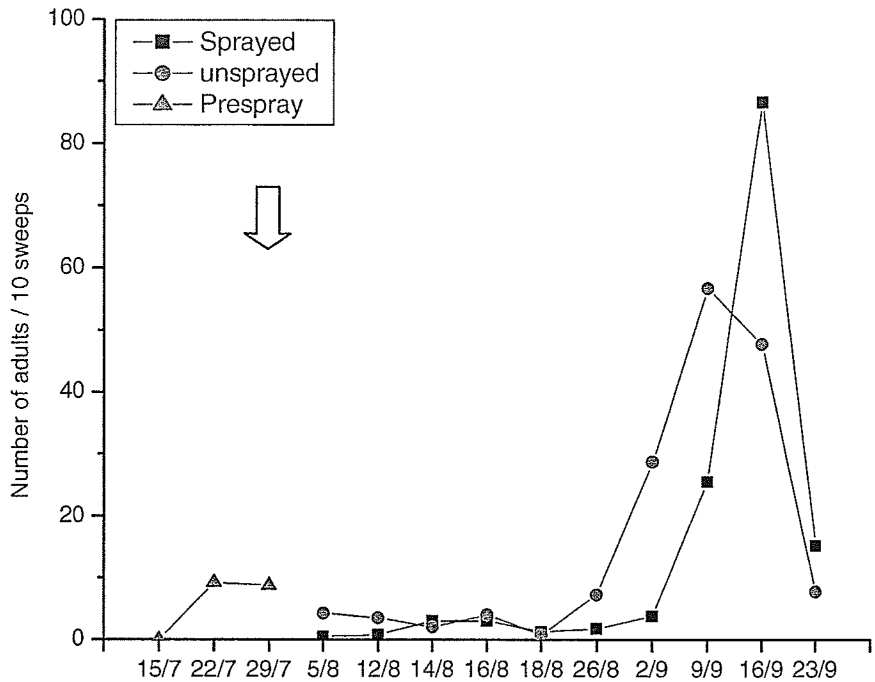

0 *Lygus*
5 *Lygus*
20 *Lygus*

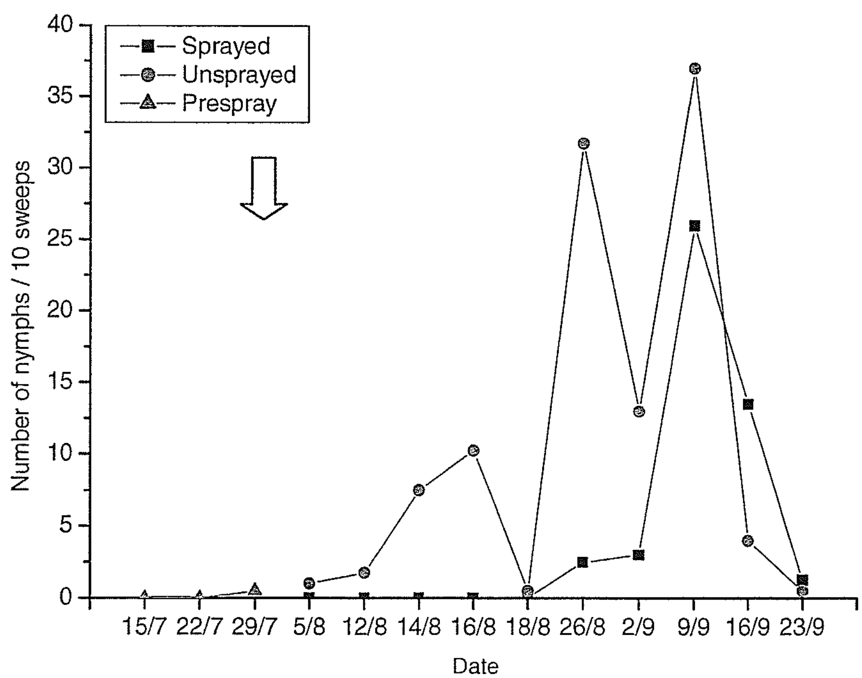
Fig. 18: Means catches of lygus bug adults (a) and nymphs (b) in sweep net samples in sprayed and unsprayed sections of a buckwheat plot at Carman in 2002. The arrow denotes the date of application of insecticide.

(a)



Sprayed
unsprayed
Prespray
Number of adults / 10 sweeps
0
20
40
60
80
100
15/7 22/7 29/7 5/8 12/8 14/8 16/8 18/8 26/8 2/9 9/9 16/9 23/9

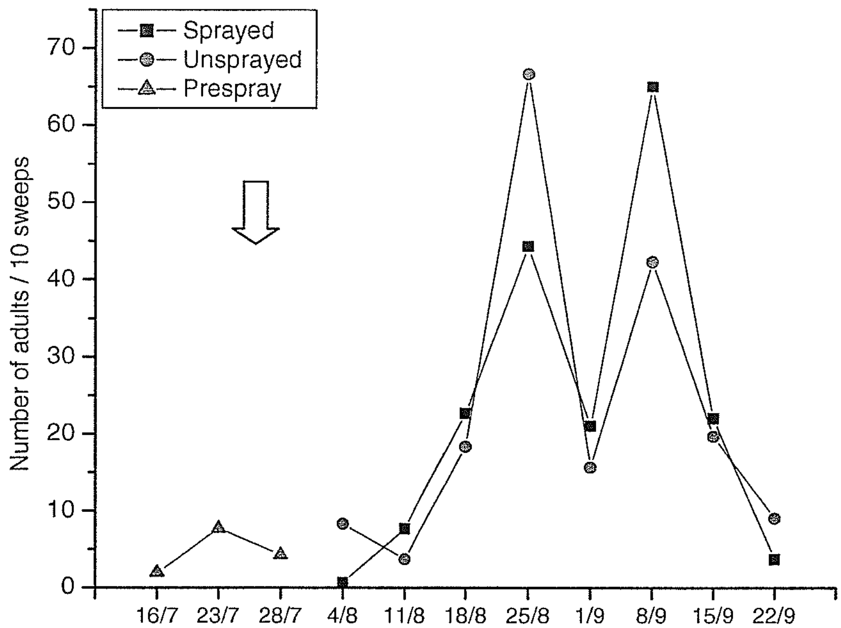
(b)



Sprayed
Unsprayed
Prespray
Number of nymphs / 10 sweeps
0
5
10
15
20
25
30
35
40
15/7 22/7 29/7 5/8 12/8 14/8 16/8 18/8 26/8 2/9 9/9 16/9 23/9
Date

Fig. 19: Mean catches of lygus bug adults (a) and nymphs (b) in sweep net samples in sprayed and unsprayed sections of a buckwheat plot at Carman in 2003. The arrow denotes the date of application of insecticide.

(a)


Sprayed
Unsprayed
Prespray
Number of adults / 10 sweeps
0
10
20
30
40
50
60
70
16/7
23/7
28/7
4/8
11/8
18/8
25/8
1/9
8/9
15/9
22/9

(b)

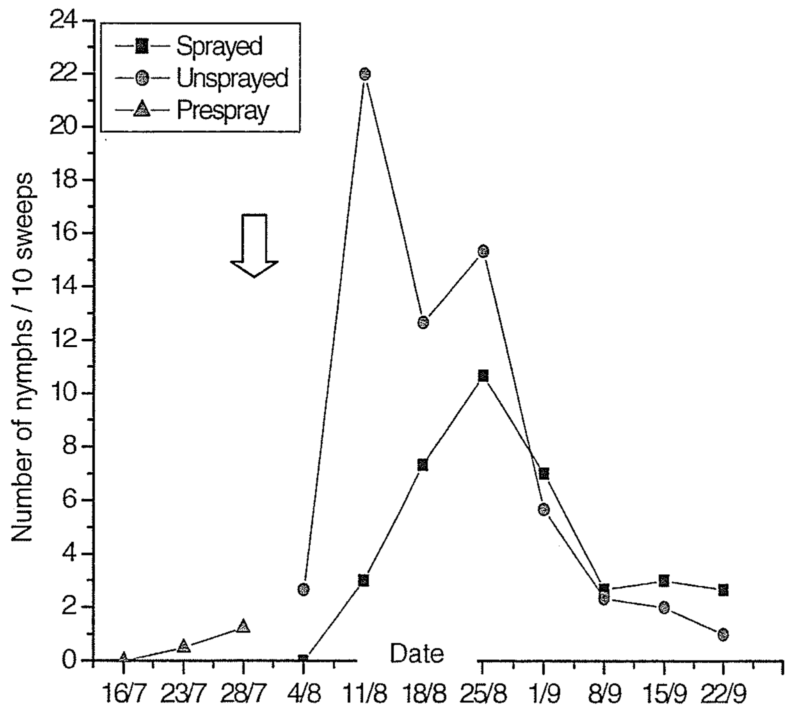
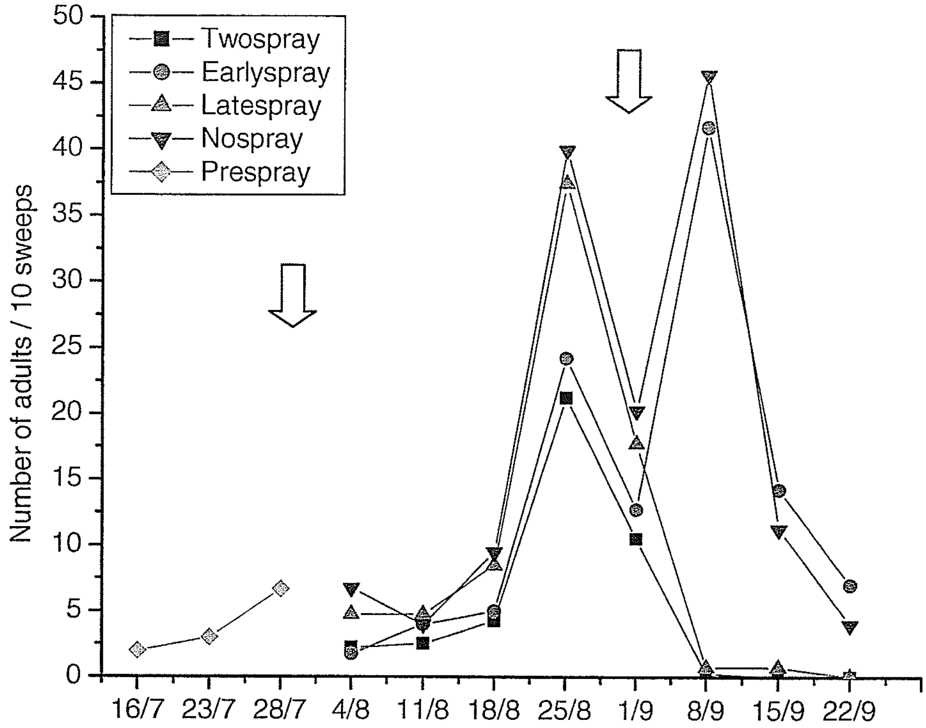

Sprayed
Unsprayed
Prespray
Number of nymphs / 10 sweeps
0
2
4
6
8
10
12
14
16
18
20
22
24
Date
16/7
23/7
28/7
4/8
11/8
18/8
25/8
1/9
8/9
15/9
22/9

Fig. 20: Mean catches of lygus bug adults (a) and nymphs (b) in sweep net samples in buckwheat plots with four different insecticide treatments at Altamont, MB in 2003. The arrow denotes the dates of application of insecticide.

(a)


Twospray
Earlyspray
Latespray
Nospray
Prespray
Number of adults / 10 sweeps
50
45
40
35
30
25
20
15
10
5
0
16/7
23/7
28/7
4/8
11/8
18/8
25/8
1/9
8/9
15/9
22/9

(b)

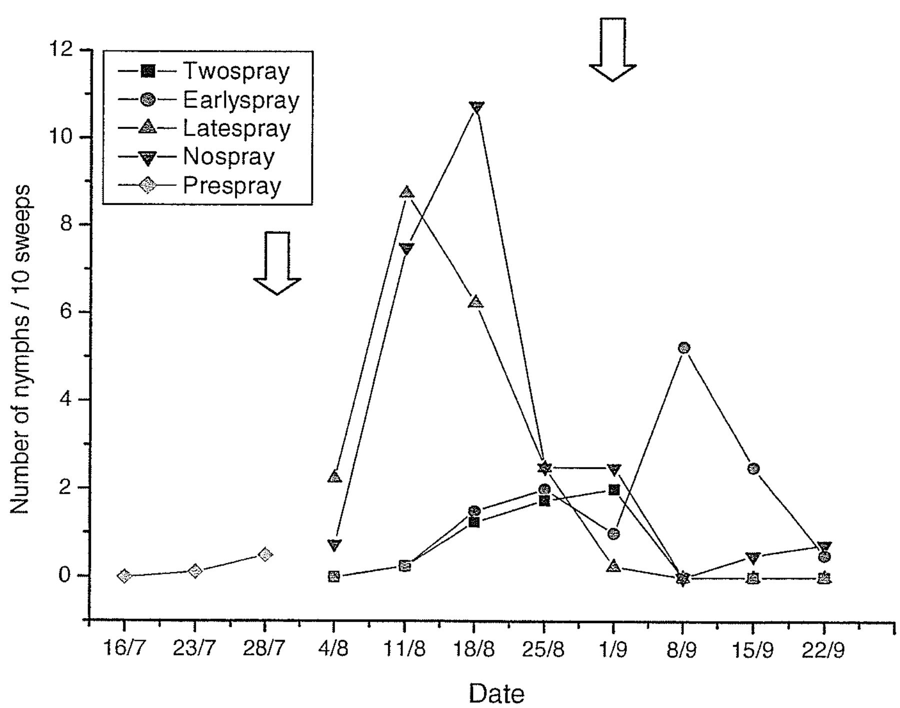
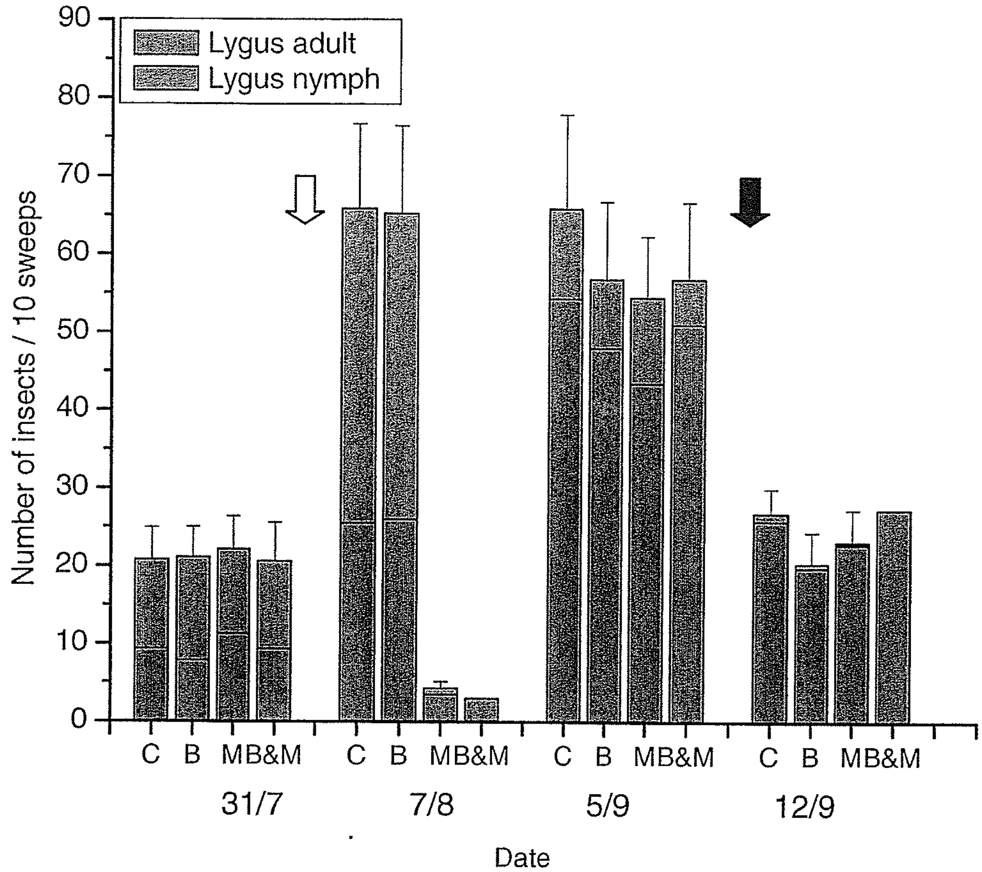

Twospray
Earlyspray
Latespray
Nospray
Prespray
Number of nymphs / 10 sweeps
12
10
8
6
4
2
0
16/7
23/7
28/7
4/8
11/8
18/8
25/8
1/9
8/9
15/9
22/9
Date

Fig. 21: Mean catches of lygus bug adults and nymphs in sweep net samples before and after treatments of Matador® and Botanigard® in buckwheat at the University of Manitoba Campus in 2003. The open arrow denotes the date of Matador® application and the solid arrow denotes the date of Botanigard® application. C = Control; M = Matador®; B = Botanigard®; B&M = Matador® in early season and Botanigard® in late season.



Lygus adult
Lygus nymph
Number of insects / 10 sweeps
0
10
20
30
40
50
60
70
80
90
C B MB&M
C B MB&M
C B MB&M
C B MB&M
31/7
7/8
5/9
12/9
Date

Fig. 22: Mean catches of adult and nymph lygus bugs in sweep net samples before and after treatments of Matador® and Botanigard® in buckwheat at the University of Manitoba Campus in 2004. The open arrow denotes the date of Matador® application and the solid arrow denotes the date of Botanigard® application. C = Control; M = Matador®; B = Botanigard®; B&M = Matador® in early season and Botanigard® in late season.

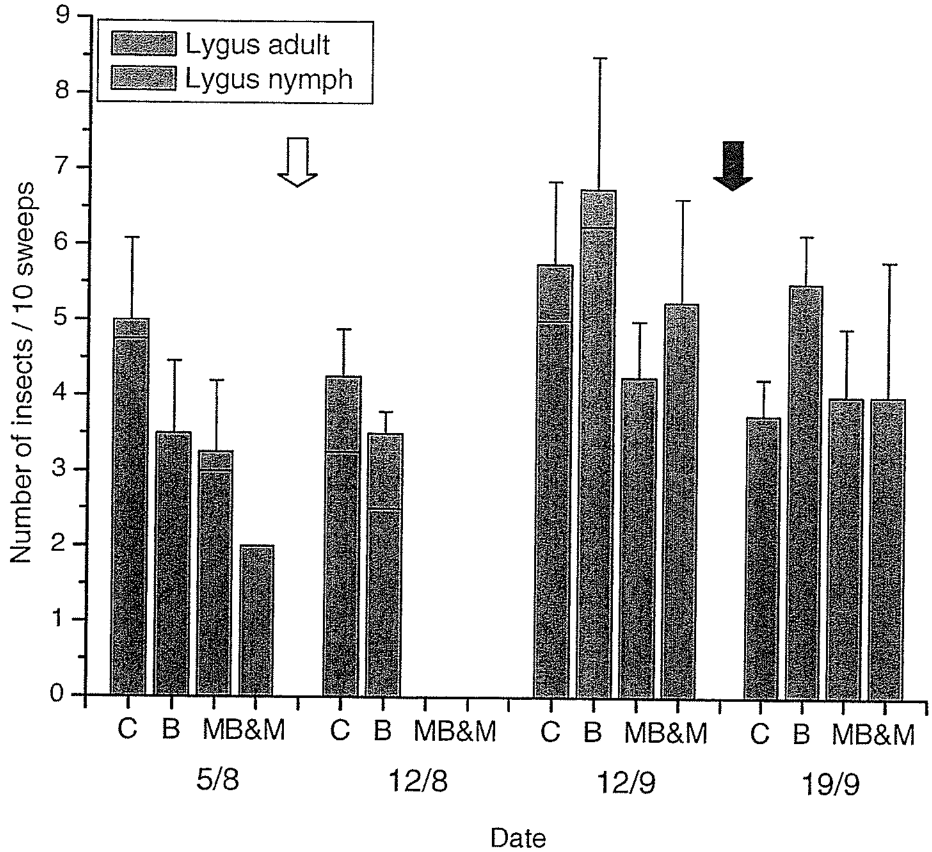
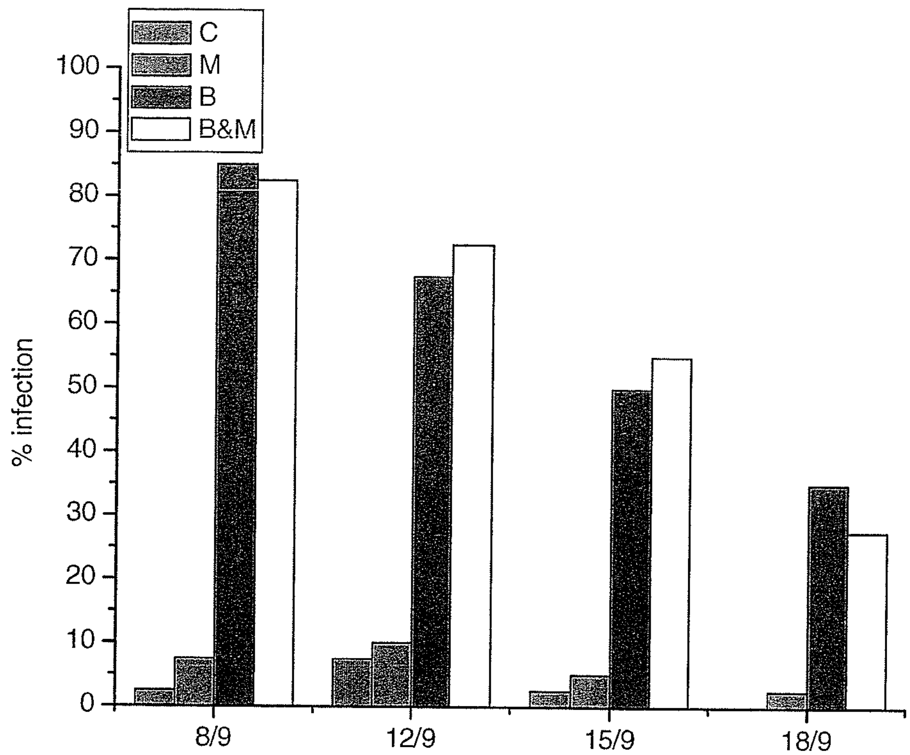

Lygus adult
Lygus nymph
Number of insects / 10 sweeps
0
1
2
3
4
5
6
7
8
9
C B MB&M C B MB&M C B MB&M C B MB&M
5/8
12/8
12/9
19/9
Date

Fig. 23: Percentage of infection of lygus bugs with fungus after the application of Botanigard® in buckwheat on 5 September, 2003 (a) and on 12 September 2004 (b). C = Control; M = Matador®; B = Botanigard®; B&M = Matador® in early season and Botanigard® in late season.

(a)


C
M
B
B&M
100
90
80
70
60
50
40
30
20
10
0
% infection
8/9
12/9
15/9
18/9

(b)

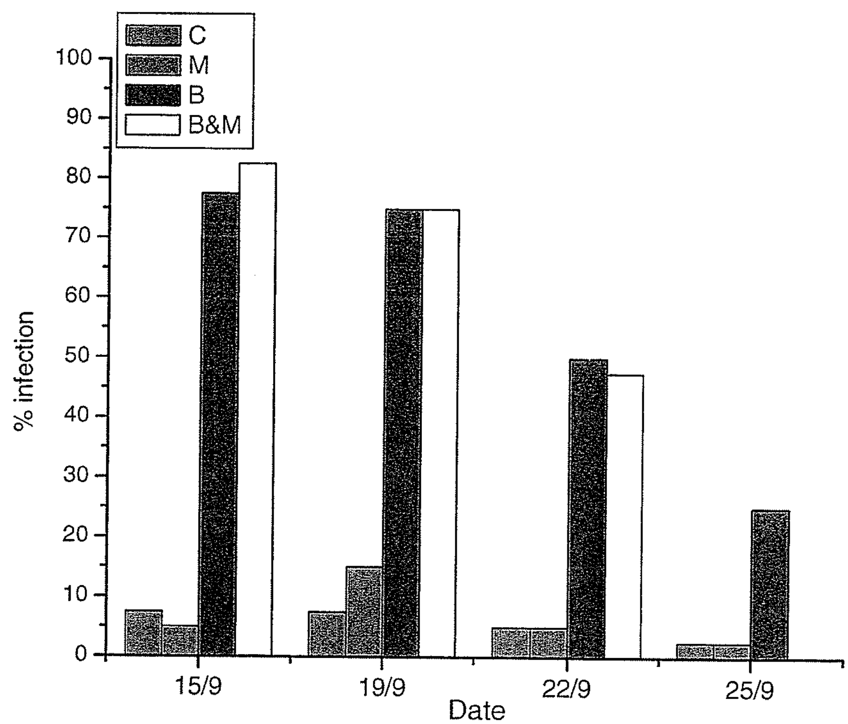
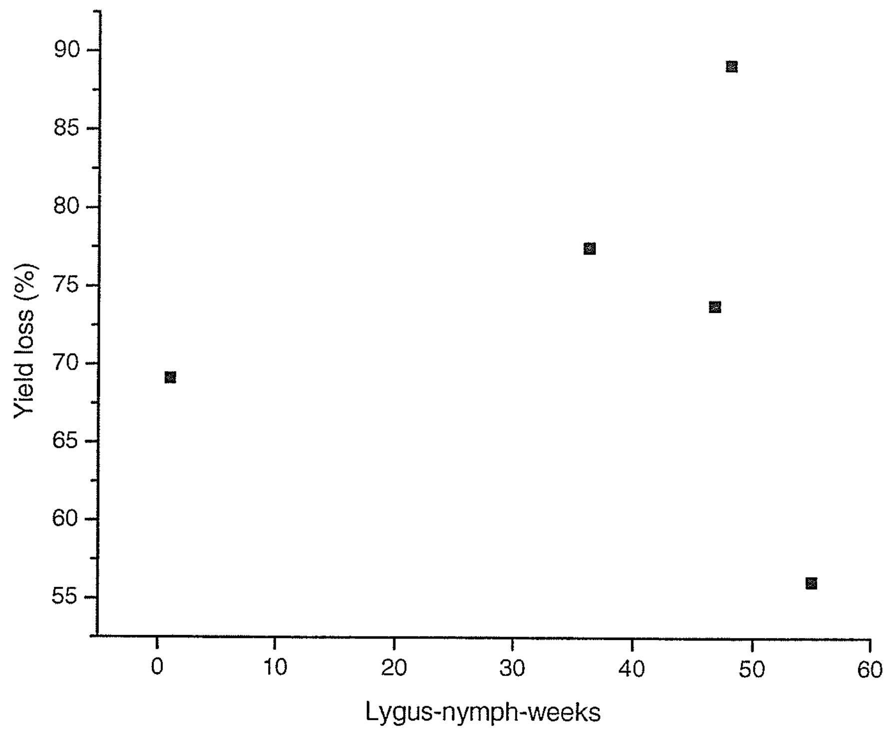

C
M
B
B&M
100
90
80
70
60
50
40
30
20
10
0
% infection
15/9
19/9
22/9
25/9
Date

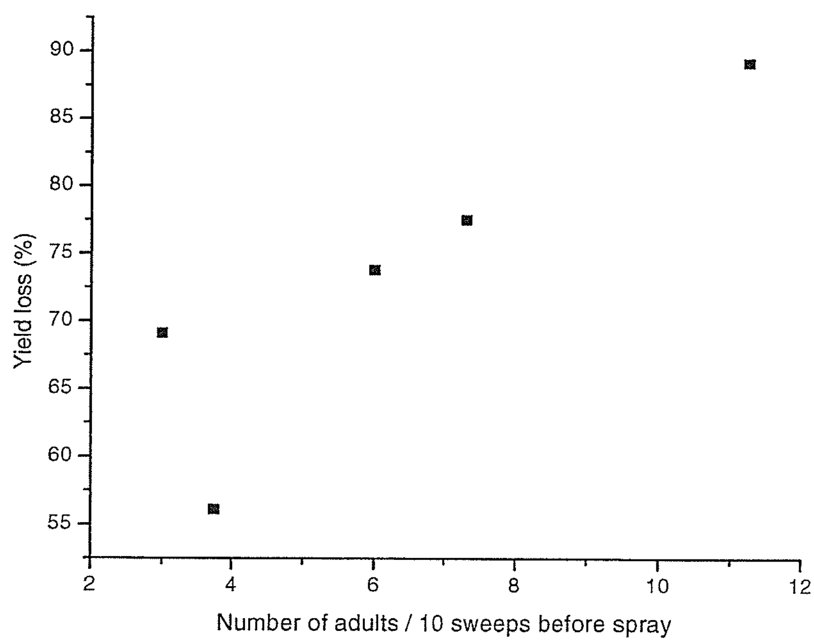
Fig. 24: Percentage of yield loss in untreated check compared to the yield from the early insecticide application of Matador® in response to lygus bug nymph weeks (a) and number of lygus bug adults during the week before the insecticide treatment (b) in five different trials.

(a)



Yield loss (%)
90
85
80
75
70
65
60
55
0
10
20
30
40
50
60
Lygus-nymph-weeks

(b)



Yield loss (%)
90
85
80
75
70
65
60
55
2
4
6
8
10
12
Number of adults / 10 sweeps before spray

CHAPTER III – PART 4

The role of late season plant bugs on seed alfalfa production in southern Manitoba

Abstract

The effect of late season populations of plant bugs (*Lygus* spp. and *Adelphocoris* spp.) on the seed alfalfa crop in Manitoba was investigated by manipulating populations of lygus bugs and alfalfa plant bugs using insecticide applications in August and September. Insecticide applications strongly affected numbers of plant bug in sweep net samples. However, there was no evidence that the reduction in numbers of plant bugs affected weight of seed alfalfa yield, pod weight /m^2, pod number /m^2, seed number /pod, seed number /m^2, 100 seed weight, or seed germination rate or the prevalence of hard seed . Insect numbers encountered in the experiments were typical of those in Manitoba seed alfalfa crops late in the growing season. The current practice of applying an insecticide to control late season populations of plant bugs appears to be economically unjustified.

Introduction

Alfalfa, *Medicago sativa* L., is the most important forage legume in Canada and was introduced to the country in 1871 (Goplen et al. 1987). An important component of the insect pest fauna of alfalfa in western Canada is two groups of plant bugs, the alfalfa plant bug, *Adelphocoris* spp. (Hemiptera: Miridae) and plant bugs of the genus *Lygus* of which the most abundant is the tarnished plant bug, *Lygus lineolaris* (Palisot de Beauvois) (Hemiptera: Miridae) (Goplen et al. 1987; Soroka 1991; Harris 1992; Schaber 1992; Uddin 2005).

In Manitoba, two production systems are used for alfalfa; hay and alfalfa seed (Uddin 2005). Insect pests in hay fields are disturbed by two or more harvests, which keep them at low levels that usually do not cause economic damage. However, the same pests have the potential to cause economic damage to seed alfalfa where the plants, especially the reproductive tissues, are exposed to the insect attack throughout most of the season.

The main method for preventing this damage in North America is use of insecticides. When producers in Saskatchewan and Manitoba make decisions about the need for control for plant bugs, it is usual for them to consider the sum of the two types of mirid plant bugs, and a commonly used threshold for determining whether control is needed is 5 mirid bugs per 180° sweep of a sweep net at bud formation and flowering stage (Soroka 1991). Eight plant bugs or four nymphs at 4th and 5th instar and four adults per sweep at the bud and flowering stage justify early season insecticide applications in Alberta (Schaber and Richards 1979; Schaber 1992), and 12-16 plant bugs per sweep at pod formation is suggested as a late season threshold in Saskatchewan (Harris 1992). Alfalfa plant bugs infesting the crop late in the growing season, in August and September at the time of formation of pods, have no effect on the seed yield of alfalfa in Saskatchewan (Soroka and Murrell 1993). The growers' norm in Manitoba is to apply an insecticide in late June just before introduction of leaf-cutting bees for pollination, as a clean-up treatment for control of pests including plant bugs (Uddin 2005). When leaf-cutting bees are removed from the seed crop in August, producers often notice high numbers of plant bugs. These numbers may exceed the early season threshold, and as a result some producers apply insecticide about the third week ofAugust, although the effects of plant bugs at this time are not well understood.

Although growers use the early season threshold to justify the late season insecticide application, there is no information available to support using that early-season threshold in August. It is likely that thresholds for August would differ from early season thresholds because of the differences in insect population structure (Murrell 1987; Soroka and Murrell 1993; Uddin 2005) and the plant physiological stage (Goplen et al. 1987). The objective of this research was to develop an appropriate threshold for use late in the growing season by examining how alfalfa seed yield and quality relate to plant bug populations at that time. The main experimental method used was manipulation of populations of plant bugs in plots in commercial seed fields in August and September using insecticide.

Materials and Methods

The effects of plant bugs (Family Miridae: Order Hemiptera), mainly *Lygus* spp. and *Adelphocoris* spp., on yield parameters of alfalfa cultivated for seed production were studied in commercial fields late in the growing seasons of 2002 - 2004. These fields had received an insecticide application in late June to control the populations of these plant bugs before pollinators were introduced. To estimate the effects of plant bug populations late in the season, the numbers of plant bugs were manipulated using applications of the insecticide Matador® (cyhalothrin-lambda, 120 g/L) at the rate of 83 ml product/ha, using a bicycle sprayer in 2002 and a tractor-mounted sprayer in 2003 and 2004.

In 2002, 9 plots, each 20 x 30 m, were measured and marked in a commercial field near Teulon, Manitoba two weeks before the anticipated time of late season insecticide application. In the nine plots, three treatments were replicated three times in a randomized complete block design (Table 22). The three treatments were: 1) an insecticide application at the same time the grower applied insecticide to suppress late season populations of plant bugs (One spray); 2) two insecticide applications, one at the same time as the grower applied insecticide and a second application to suppress later adult immigrants (Two spray; 3) no insecticide application (No spray).

At weekly intervals starting the week after the first insecticide application and continuing until the harvest of the crop, a sample of 10 sweeps was taken along the diagonal of each plot using 180° sweeps of a net with a 40 cm diameter. To obtain estimates of pre-treatment numbers of insects, 10 sweeps were made at five sample sites in an adjacent 20 x 30 m plot during the two weeks before the first insecticide application. Samples were put in Ziploc® bags and kept in an insulated cooler with freezer packs for transport to the laboratory where they were frozen to kill and preserve the specimens. Lygus bug adults were identified to species, and alfalfa plant bug adults were identified to genus using the keys of Kelton (1975, 1980), Schwartz and Foottit (1992a) and Mueller et al. (2003). Nymphs were identified to the generic level, and separated into two groups: 1st to 3rd instar and 4th to 5th instar.

Two 1-m^2 areas were hand harvested from each plot in September 2002. The harvested materials were kept separately in cloth bags and allowed to air dry. Alfalfa pods were picked from the harvested material by hand, and then threshed using a belt threshing machine in the laboratory. The numbers of pods per m^2 and number of seeds per 100 pods were counted. Seed harvest per m^2 was weighed and number of seeds per m^2 was calculated. A germination trial for sub-samples of 200g, or for the whole 1 m^2 yield if less than 200g, was conducted by ACCU-Test Seed Lab., Rivers, Manitoba, Canada using standard protocols of the Commercial Seed Analysis Association of Canada.

In the 2003 and 2004 seasons, sixteen plots, each 20 x 30 m, were marked by metal stakes in mid August in commercial seed alfalfa fields in Manitoba near Riverton and Arborg, Manitoba, respectively. The same insecticide treatments were used as in 2002 with the addition of a fourth treatment, a single insecticide application at the time of the second insecticide application in the two spray treatment to target only immigrant adults (Table 22). The treatments were replicated four times in a randomized complete block design. Samples of 10 (180^o) sweeps were taken along the diagonal of each plot at weekly intervals from the time of marking the plots until the time of crop desiccation. Insect sampling procedures were as in the 2002 trial.

Seed alfalfa fields were desiccated 5 and 11 days after the second application of Matador in 2003 and 2004, respectively. On 11 September 2003 and 29 September 2004, four 1 m^2 areas were hand swathed from each plot. The harvested materials were gathered and allowed to air dry in cloth bags, threshed using a stationary threshing machine and cleaned using different mesh screens. Seed weight and pod number per m^2 and seed number per 100 pods and per m^2 were estimated. Two weeks later, 150 m^2 and 112.5 m^2 from each plot were harvested in 2003 and 2004, respectively, using a plot combine harvester. The harvested material was allowed to dry in cloth bags and threshed and cleaned as for the hand harvested material. The weight of the harvested seeds per m^2 from the machine harvest was assessed.

Germination trials were conducted for both hand and machine harvested yields of 2003 and 2004, using the same procedures as in 2002.

Statistical analysis

When necessary, $\log_{10}X$ or $\log_{10}(X + 1)$ transformations were used for numerical data other than percentages to reduce heteroscedasticity. The arcsine transformation was used for percentages. Two way analysis of variance was performed for the randomized complete block design for each commercial field trial. A one tailed Dunnett's test was used to determine the significances of differences of the mean of the untreated control from the mean of each insecticide treatment. A significance level of 0.05 was adopted and all analyses were conducted using Systat® 10, or higher, software (SPSS 2000).

Results

Responses of plant bug numbers to insecticide applications

In 2002, pre-treatment sampling showed that about six lygus bugs per 10 sweeps were present (Fig. 25a & b). Alfalfa plant bug adults started with higher numbers before the first insecticide application (Fig. 26a). The number of alfalfa plant bug nymphs remained below three insects per 10 sweeps in the adjacent plot (Fig. 26b). With the exception of a small number of lygus bug nymphs in the two spray treatment (Fig. 25b), no nymphs were found in the insecticide treated plots following the first application. The first insecticide application effectively decreased the numbers of adult lygus bugs and alfalfa plant bugs (Fig. 25a, 26a). After the second insecticide application, the two spray and the no spray treatments had no lygus bug adults or nymphs (Fig. 25a & b). After the second insecticide application, no nymphs, and only one alfalfa plant bug adult per 10 sweeps in the no spray and one spray treatments were found (Fig. 26a & b).

In 2003, lygus bug adults ranged from 0.25 to 4.25 per 10 sweeps during the two weeks before the first insecticide application then declined the week after the early spray and that pattern persisted until harvest (Fig. 27a). The numbers of lygus bug nymphs were low during the 2 weeks before the first insecticide application (Fig. 27b) and plots receiving the first insecticide application had no lygus nymphs until the end of the trial (Fig. 27b), although nymphal numbers were low in all treatments from one week after the first application. Alfalfa plant bug adult numbers were about 10 per 10 sweeps before the first insecticide application (Fig. 28a). In plots receiving this application, alfalfa plant bug adult numbers were < 1/20th of those in untreated plots the week after the application, although numbers in different treatments became similar thereafter (Fig. 28a). Numbers of alfalfa plant bug nymphs exceeded 14 per 10 sweeps immediately before the first insecticide application, and these numbers decreased in all treatments after this application (Fig. 28b). The five day interval between late spray and crop desiccation did not provide an opportunity for sampling.

In general, catches of lygus bug adults and nymphs were higher in 2004 than in the previous years but numbers of alfalfa plant bug were lower than in 2003. In 2004, numbers of lygus bug adults before insecticide treatments ranged from 17 to 36 adults per 10 sweeps (Fig. 29a); in plots receiving the first application, numbers after the application were close to zero and recovered only slightly before the end of the season (Fig. 29a). The week after the second insecticide application, numbers of lygus bug adults dropped to zero in the treated plots, and ranged from 5 to 16 per 10 sweeps in other treatments (Fig. 29a). Lygus bug nymph numbers ranged from 6 to 22 per 10 sweeps before the first insecticide application (Fig. 29b). That application reduced numbers to almost zero in the treated areas (Fig. 29b). After the second week following the first insecticide application, numbers of lygus bug nymphs were low in all treatments (Fig. 29b). Catches of alfalfa plant bug adult were between 6 and 10 per 10 sweeps before the first insecticide application (Fig. 30a). Following the application, the numbers of alfalfa plant bug adults were low compared with untreated plots, but recovered somewhat by the time of the second application (Fig. 30a). The second application reduced the number of alfalfa plant bug adults to almost zero in the treated plots (Fig. 30a). Catches of alfalfa plant bug nymphs before the first insecticide application ranged from 5 – 10 nymphs per 10 sweeps (Fig. 30b), and in the treated plots numbers were close to zero immediately following the application, but rose slightly later in the season (Fig. 30b). By the time of the second insecticide application, alfalfa plant bug nymph numbers were quite low in all treatments (Fig. 30b).

The mean total numbers of plant bugs per sweep in different treatments before the first insecticide treatment in 2004 were higher than in the other two years, but in only two treatments did they exceed 5 bugs / sweep (Table 23). After the first insecticide treatment, plant bug numbers decreased in all treated areas (Table 23). After the second insecticide treatments, these numbers were less than 1 bug / sweep except for the untreated check although densities were relatively low in the check also (Table 23).

Responses of alfalfa seed yield parameters to insecticide applications

Only hand harvest yield data were collected in the 2002 trial. Although seed weight/m^2, seed number / 100 pods and seed number/m^2 tended to be higher in the treatment with two sprays than in other treatments, treatment effects were not significant for any of the yield quantity parameters (Table 24). Treatment also had no significant effect on 100 seed weight, although the two-spray treatment tended to have lighter seeds than other treatments. Neither percentage of seed germination nor the percentage of hard seed (the seed that does not germinate within the expected time of germination, but has potential to germinate later) was significantly affected by the treatments (Table 24).

In 2003 and 2004, neither the seed yield per m^2 for either harvest method nor the seed quality estimates were affected by any of the insecticide treatments (Tables 25 & 26).

Analysis of the relationship between plant bug weeks after the first spray and the yield in the untreated check as percentage of yield in the early spray treatment during the three years of trials showed no significant correlation between the two measurements ($r = 0.6$, $P>0.1$) (Fig. 31a). The yields in the untreated check were higher than in the areas that received the early insecticide treatment except for the hand harvest yield of 2003 trial. Similar results were found when correlating these differences with the number of plant bugs before the insecticide application ($r = 0.06$, $P>0.4$) (Fig. 31b). Again, the plant bug numbers before the first spray did not affect the yield, rather the yield in the untreated checks were usually higher (Fig. 31b).

Discussion

There were no significant effects of insecticide treatments on estimates of yield parameters in 2002; however, it did appear that several yield estimates were similar between one spray and untreated check, but rather different in the two spray treatment. When these results are examined in light of the effects that treatments had on insect numbers, it appears unlikely that insects were responsible for the apparently different results in the two spray treatment. In the two weeks after the first spray, both spray treatments had similar plant bug numbers which were about 6% of those in the control and in the two weeks after the second spray, there were very few bugs in any treatment. Thus the big differences in insect numbers were between control and sprayed treatments, but the big differences in yields were between the two spray and the remaining treatments. These results suggest that the differences in yield components probably arose from other sources. Perhaps there were pre-existing differences arising from patchiness in growth and yield patterns of plants. As perennial legumes, alfalfa plants differ in their resistance to the severe winter in the Canadian Prairies, depending on the food they store in fall, the time and procedure of cutting (Goplen et al. 1987), and their adaptation to fall dormancy (Coukell 2001). Over time, local areas of an alfalfa field may become dominated by plants that share the same characteristics, and differ from plants that are more distant. The data in Table 24 support the idea that plants in the different treatments had different growth habits. In the two spray treatment, plants produced many pods each containing about four small seeds, whereas in the other treatments, seed size was larger, but there were fewer seeds per pod and fewer pods. What is clear is that there is no evidence from the 2002 trial of any significant benefit of the early spray treatment, the treatment that is equivalent to the insecticide application made by producers in the area.

The 2002 trial was more vulnerable to interference from local spatial effects because yield was estimated from only two 1 m^2 areas, and plots were replicated only three times. In 2003 and 2004, to reduce the risk of patchiness affecting yield assessments, the number of replicates was increased to four, and in addition to hand harvesting, relatively large areas were harvested by plot combine in a manner as similar to commercial practice as possible.

In 2003 and 2004, despite large influences of insecticide applications on insect numbers in plots, neither the machine harvest nor any of the yield components from hand harvesting showed any significant effect of the spray treatment. Furthermore, in both years, the machine-harvested yield was lowest in the two spray treatment, and it may be that this non-significant trend is attributable to wheel track damage from the sprayer. Wheel track damage is less likely to be detected in small hand-harvested areas.

The results obtained could not be used to derive an economic threshold for deciding whether or not an August application of insecticide is economically warranted as no positive effect of insecticide application on yield could be detected (Fig. 31a & b). The numbers of plant bugs at the time of August applications of the insecticides were often lower than the 5 bugs per sweep of the early season threshold but the unsprayed plot did reach 13.2 bugs / sweep (Table 23). These numbers, and lower, are fairly typical of those seen in 6 years of sampling alfalfa in Manitoba (Data in this thesis; Uddin 2005). Although the number of plant bugs exceeded the 5 bugs per sweep in 2004, there was no evidence of effects on yield quantity or quality. There was no suggestion (Fig. 31) that bugs were having any influence on yield within the range of numbers observed and so it seems likely that, if late season plant bugs do cause economic loss, this occurs at much higher numbers than observed in this study. There is a use of an action threshold of 12-16 plant bugs per sweep in Saskatchewan (Murrell 1987; Harris 1992), and it is clear that plant bug populations did not reach this level in Manitoba over the three years of my study, except in the check control treatment in 2002, where there was no significant effect on the crop yield. A previous three year study in the same area (Uddin 2005) showed that numbers of plant bugs in my study were not unusually low, but quite typical.

No damage signs of any of the five categories of plant bug injuries were observed in this study. Most pods at the time of sampling during three years of trials were in the yellow to brown stage (Goplen et al. 1987), a stage when the pods are almost matured. Plant bug injury when pods are mature does not affect the yield of alfalfa (Sedivy 1972), and this observation has been confirmed for alfalfa late in the growing season (Soroka and Murrell 1993). The population structure of plant bugs in seed alfalfa in Manitoba late in the season might also play a role in the interrelationship with alfalfa plant. At this time, most of the population are adults, which tend to feed less than nymphs (Broersma and Luckmann 1970; Khattat and Stewart 1975; Stewart and Khattat 1980a & b; Schaefers 1980; Mailloux and Bostanian 1988; Handley and Pollard 1993a & b; Easterbrook 2000). Adult lygus bugs are active movers that spend considerable amounts of time searching for suitable hosts. At the end of the growing season, adults may feed less as they prepare for overwintering (Ridgway and Gyrisco 1960a & b)

In the three years of experiments, I found that an application of insecticide in August, at the time when many producers currently make an application, did not affect yield or quality of the seed. The numbers of plant bugs just before the application of insecticide ranged from 0.75 to 5.8 per sweep, and the numbers in untreated plots were 2.7 to 13.2 per sweep during the trials. These numbers appear to be relatively typical of late season plant bug numbers in seed alfalfa in Manitoba (Uddin 2005). It is possible that much higher numbers of plant bugs in August would cause significant losses, especially if they were synchronized with plants in the green pod stage. However, under the conditions experienced in commercial fields during my study, there was no hint of yield benefit from suppressing late season populations of plant bugs, and growers should be encouraged to desist from spray applications for this purpose.

Table 22: Date of the applications of Matador® in seed alfalfa at Teulon 2002, Riverton 2003 and Arborg 2004

Treatment	2002	2003	2004
Early application	29 Aug	14 Aug	24 Aug
Two applications	29 Aug, 12 Sep	14 Aug, 4 Sep	24 Aug, 14 Sep
No application	---	---	---
Late application	---	4 Sep	14 Sep

Table 23: Average total numbers of plant bugs per sweep for the two week period before and after each application in 2002, 2003 and 2004

	Two spray			Early spray			Late spray			Untreated check		
	2002	2003	2004	2002	2003	2004	2002	2003	2004	2002	2003	2004
Before 1st spray	0.8	2.7	4.0	0.8	2.5	5.8	NA	2.7	5.6	0.8	2.2	5.8
After 1st & before 2nd spray	0.4	0.7	0.50	0.3	0.7	0.6	NA	2.5	5.1	13.2	2.7	5.3
After 2nd spray	0.0	NA	0.0	0.2	NA	0.8	NA	NA	0.0	0.1	NA	1.8

Table 24: Estimates of mean yield parameters (±SEM) and results of analysis of variance in different insecticide treatments in seed alfalfa at Teulon, MB in 2002

Yield parameter	Two spray	One spray	Untreated check	F, *P* (df = 2, 4)
Pod weight (g/m^2)	64.5±8.6	47.5±5	43.8±3.8	3.2, 0.149
Pod number (/m^2)	5231.5±684.7	3977.0±575.2	3592.0±355.9	2.2, 0.224
Seed weight (g/m^2)	29.5±3.2	20.4±1.6	21.7±1.6	4.0, 0.113
Seed number (/100 pods)	406.0±9	269.0±20.6	324.8±36.2	5.8, 0.065
Seed number (/m^2)	21363±3289	10602±1308	11799±2147	6.6, 0.054
100 seed weight (g)	0.14±0.01	0.20±0.02	0.19±0.02	3.8, 0.119
Germination (%)	24.8±2.3	27.5±2	31.8±7	0.6, 0.577
Hard seed (%)	73.7±2.2	69.2±2.2	66.7±7	0.7, 0.556

Table 25: Estimates of mean yield parameters (± SEM) and results of analysis of variance of machine and hand harvests in different insecticide treatments in seed alfalfa at Riverton, MB in 2003

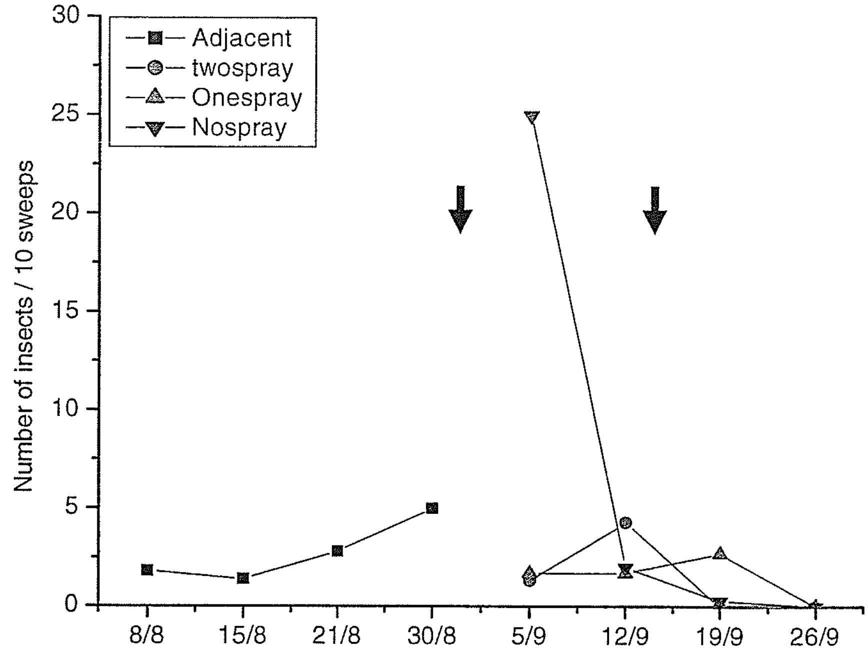
Yield Parameter	Two sprays	Early spray	Late spray	Untreated check	F, *P* (df = 3, 9)
Machine harvest					
Seed weight (g/m^2)	39.4±2.5	40.7±2.3	42.7±2.3	42.4±7.0	0.2, 0.87
Germination (%)	40.8±2.8	42.8±2.3	47.0±5.5	50.0±5.0	1.6, 0.26
Hard seed (%)	55.3±3.1	52.5±2.6	49.8±5.4	47.0±5.0	1.3, 0.33
Hand harvest					
Seed weight (g/m^2)	43.8±5.4	44.5±6.5	41.4±7.1	41.2±4.6	0.1, 0.93
100 seed weight (g)	0.17±0.01	0.16±0.01	0.16±0.02	0.15±0.01	0.7, 0.55
100 pod weight (g)	0.28±0.03	0.31±0.03	0.25±0.04	0.26±0.02	0.5, 0.67
Seed number (/m^2)	25651±2927	29093±6422	29836±9075	28815±4373	0.2, 0.87
Germination (%)	45.1±2.1	40.7±4.4	41.6±4.2	43.5±4.8	0.2, 0.87
Hard seed (%)	51.1±1.8	53.9±4.9	50.6±6.0	48.8±6.0	0.2, 0.91

Table 26: Estimates of mean yield parameters (± SEM) and results of analysis of variance of machine and hand harvests in different insecticide treatments in seed alfalfa at Arborg, MB in 2004

Yield parameter	Two sprays	Early spray	Late spray	Untreated check	F, *P* (df = 3, 9)
Machine harvest					
Seed weight (g/m^2)	20.2±3.3	20.8±3.8	21.5±3.4	21.3±2.6	0.1, 0.93
Germination (%)	50.3±1.0	50.3±2.3	50.3±1.9	53.3±3.2	0.6, 0.66
Hard seed (%)	44.0±1.1	45.5±2.2	45.0±2.2	41.8±3.5	0.5, 0.69
Hand harvest					
Seed weight (g/m^2)	18.5±2.4	17.9±1.5	18.4±2.0	19.6±1.6	0.1, 0.93
100 seed weight (g)	0.10±0.02	0.10±0.01	0.10±0.01	0.10±0.01	0.3, 0.79
100 pod weight (g)	0.25±0.05	0.23±0.03	0.26±0.1	0.21±0.02	0.3, 0.82
Seed number ($/m^2$)	24787±3781	20531±2199	19799±4229	15843±1221	1.2, 0.37
Germination (%)	52.0±1.8	50.8±2.8	50.9±2.7	50.8±0.7	0.1, 0.94
Hard seed (%)	42.8±1.5	42.9±3.1	43.3±2.6	41.4±2.2	0.1, 0.94

Fig. 25: Mean catches of (a) lygus bug adults and (b) lygus bug nymphs per 10 sweeps in seed alfalfa near Teulon, MB in 2002. Arrows denote the dates of the insecticide applications.

(a)


Adjacent
twospray
Onespray
Nospray
Number of insects / 10 sweeps
0
5
10
15
20
25
30
8/8
15/8
21/8
30/8
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12/9
19/9
26/9

(b)

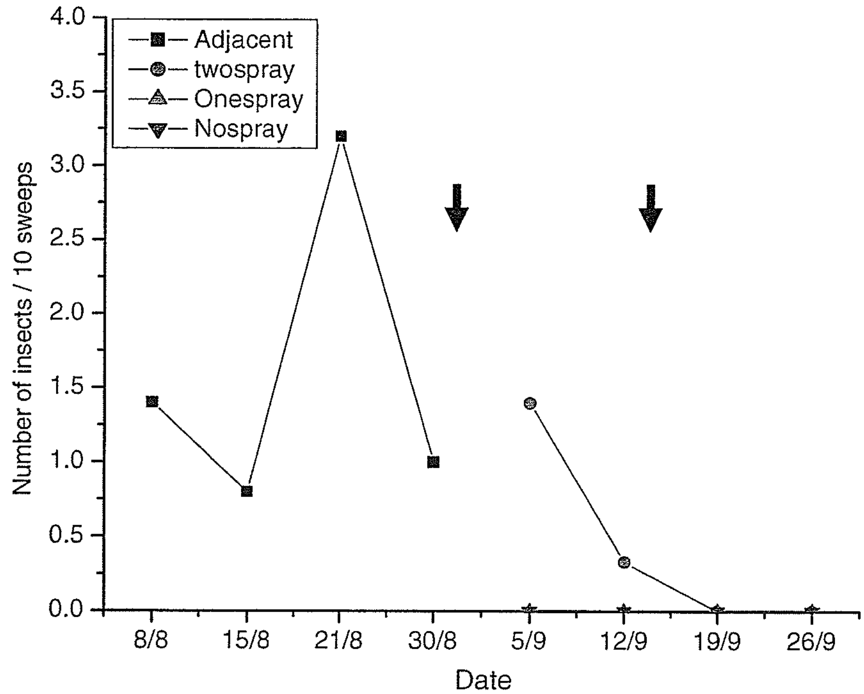
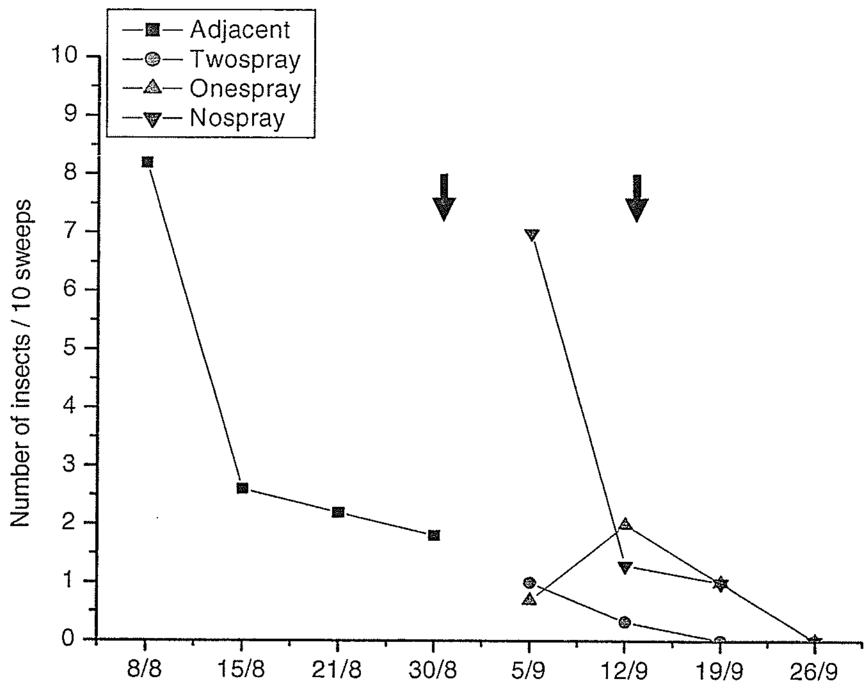

Adjacent
twospray
Onespray
Nospray
Number of insects / 10 sweeps
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
8/8
15/8
21/8
30/8
5/9
12/9
19/9
26/9
Date

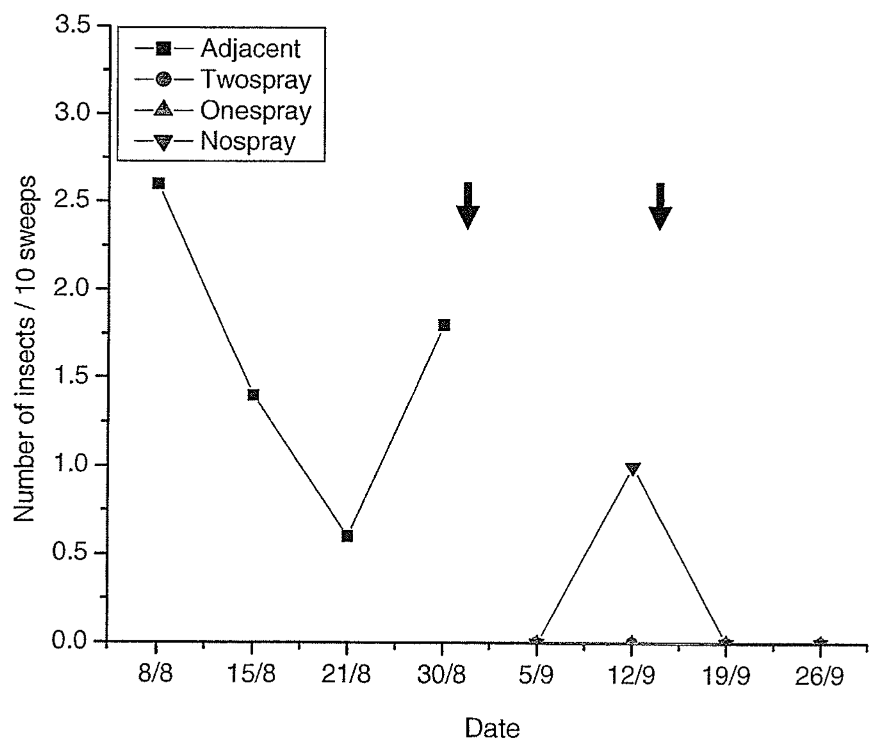
Fig. 26: Mean catches of *Adelphocoris* spp. adults (a) and nymph (b) per 10 sweeps in seed alfalfa near Teulon, MB in 2002. Arrows denote the dates of the insecticide applications.

(a)



Adjacent
Twospray
Onespray
Nospray
Number of insects / 10 sweeps
10
9
8
7
6
5
4
3
2
1
0
8/8
15/8
21/8
30/8
5/9
12/9
19/9
26/9

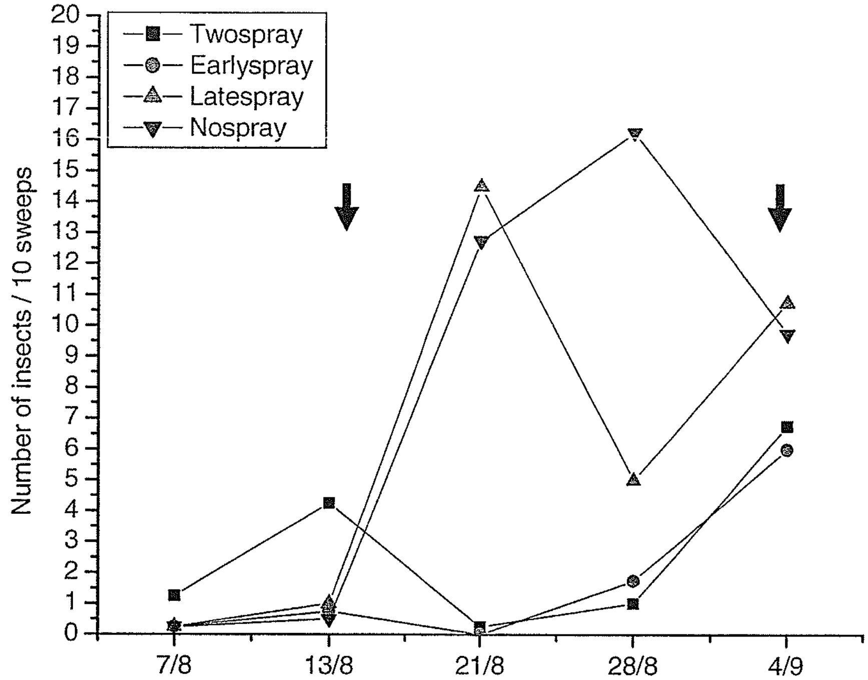
(b)



Adjacent
Twospray
Onespray
Nospray
Number of insects / 10 sweeps
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
8/8
15/8
21/8
30/8
5/9
12/9
19/9
26/9
Date

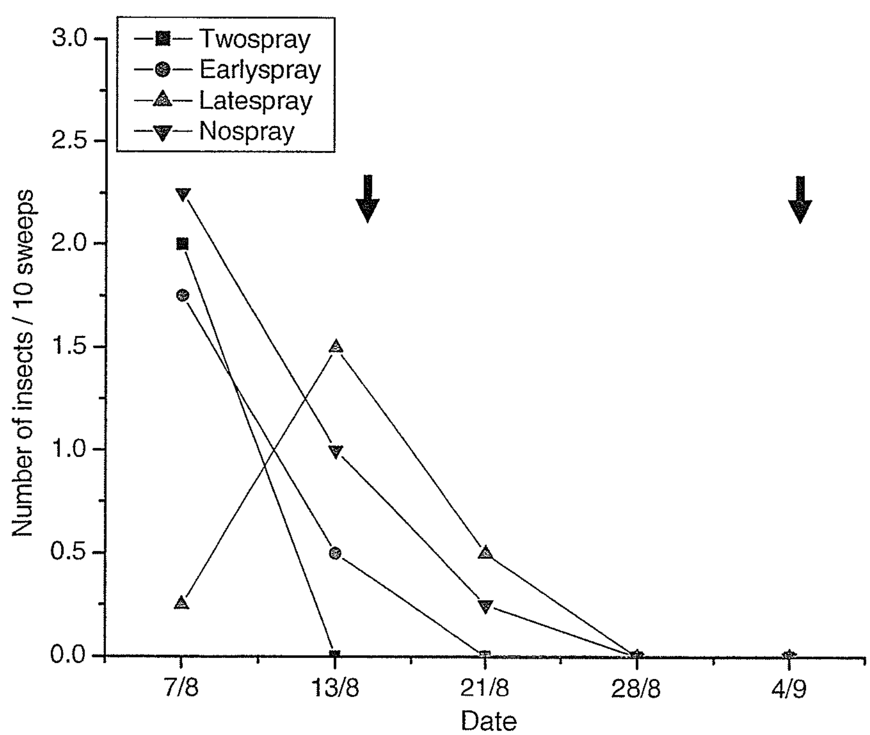
Fig. 27: Mean catches of lygus bug adults (a) and lygus bug nymphs (b) per 10 sweeps in seed alfalfa near Riverton, MB in 2003. Arrows denote the dates of the insecticide applications.

(a)



Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
7/8
13/8
21/8
28/8
4/9

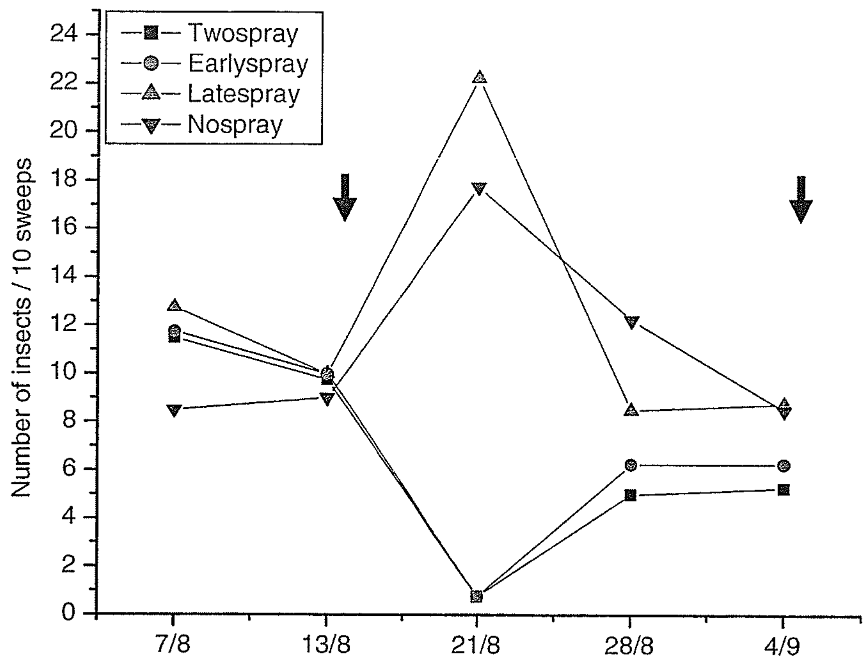
(b)



Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
7/8
13/8
21/8
28/8
4/9
Date

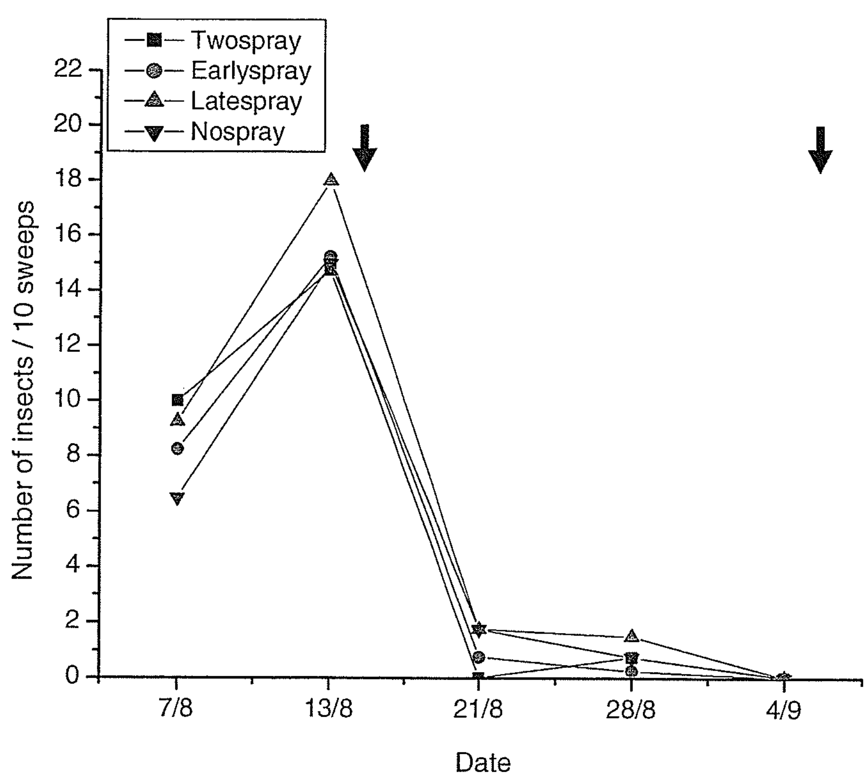
Fig. 28: Mean catches of *Adelphocoris* spp. adults (a) and nymphs (b) per 10 sweeps in seed alfalfa near Riverton, MB in 2003. Arrows denote the dates of the insecticide applications.

(a)



Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
2
4
6
8
10
12
14
16
18
20
22
24
7/8
13/8
21/8
28/8
4/9

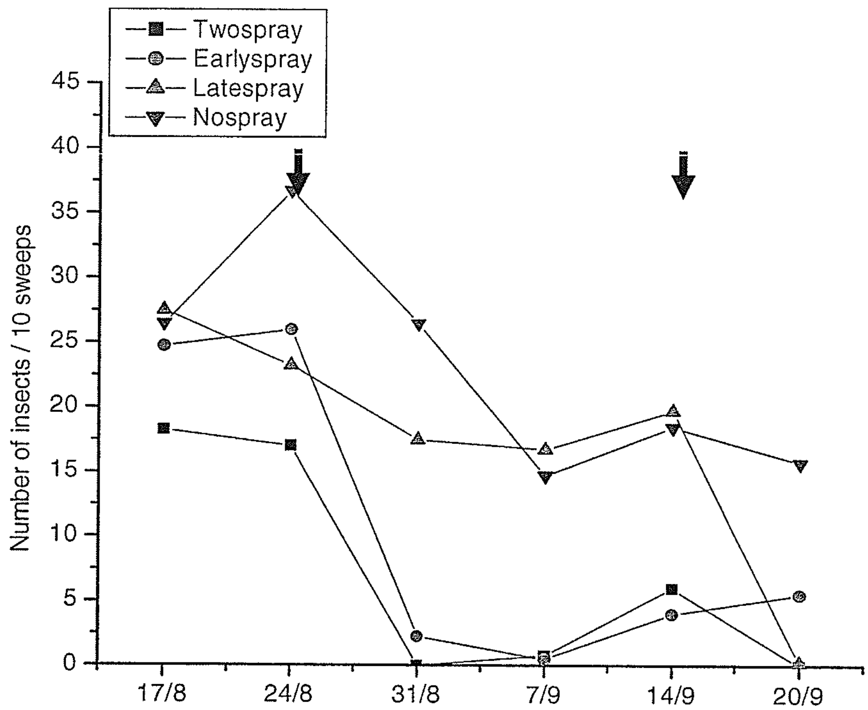
(b)



Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
2
4
6
8
10
12
14
16
18
20
22
7/8
13/8
21/8
28/8
4/9
Date

Fig. 29: Mean catches of lygus bug adults (a) and lygus nymphs (b) per 10 sweeps in seed alfalfa near Arborg, MB in 2004. Arrows denote the dates of the insecticide applications.

(a)


Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
5
10
15
20
25
30
35
40
45
17/8
24/8
31/8
7/9
14/9
20/9

(b)

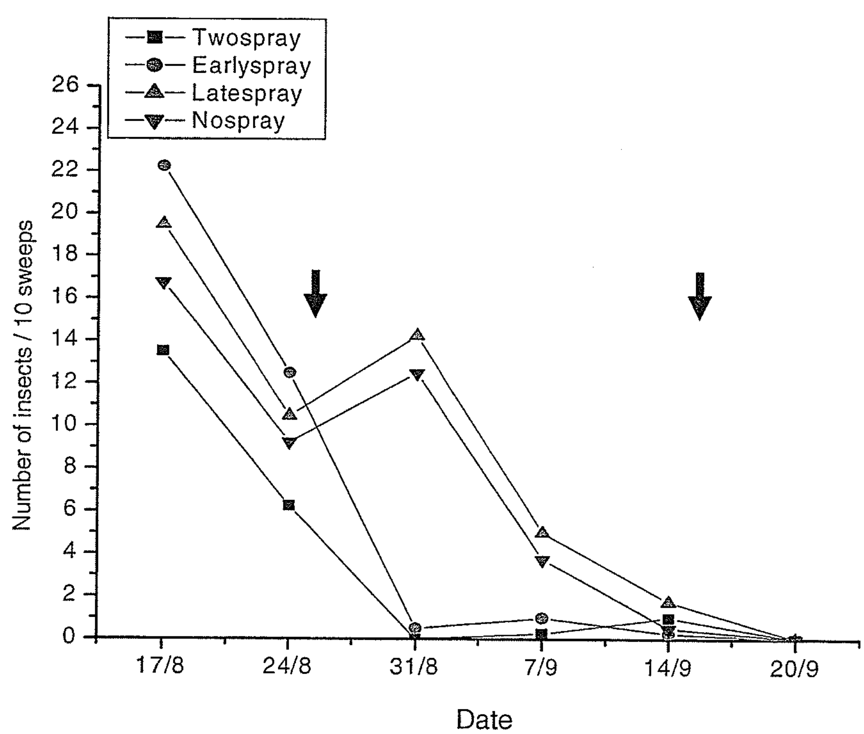
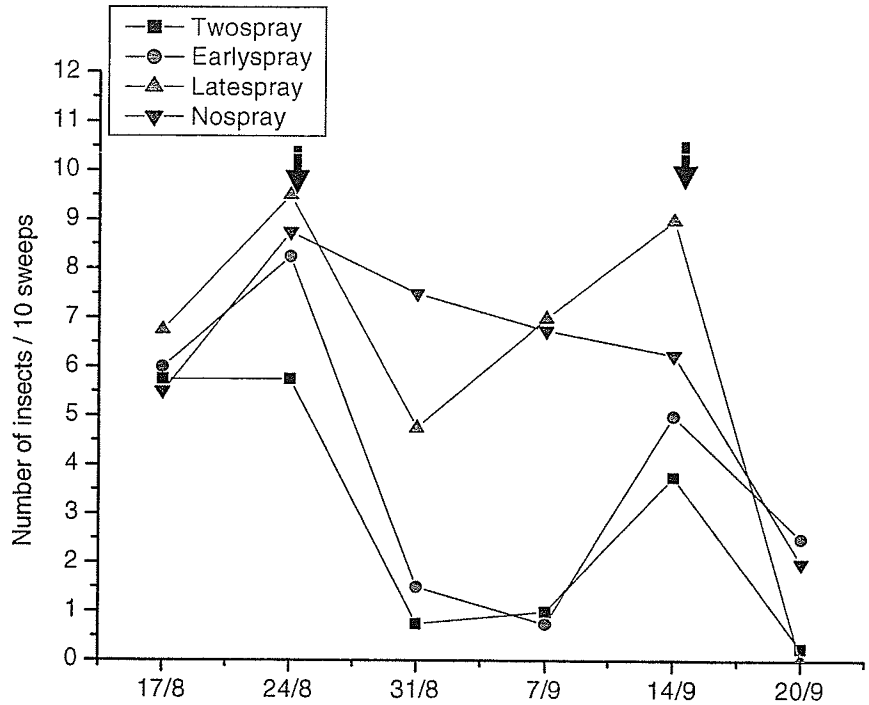

Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
2
4
6
8
10
12
14
16
18
20
22
24
26
17/8
24/8
31/8
7/9
14/9
20/9
Date

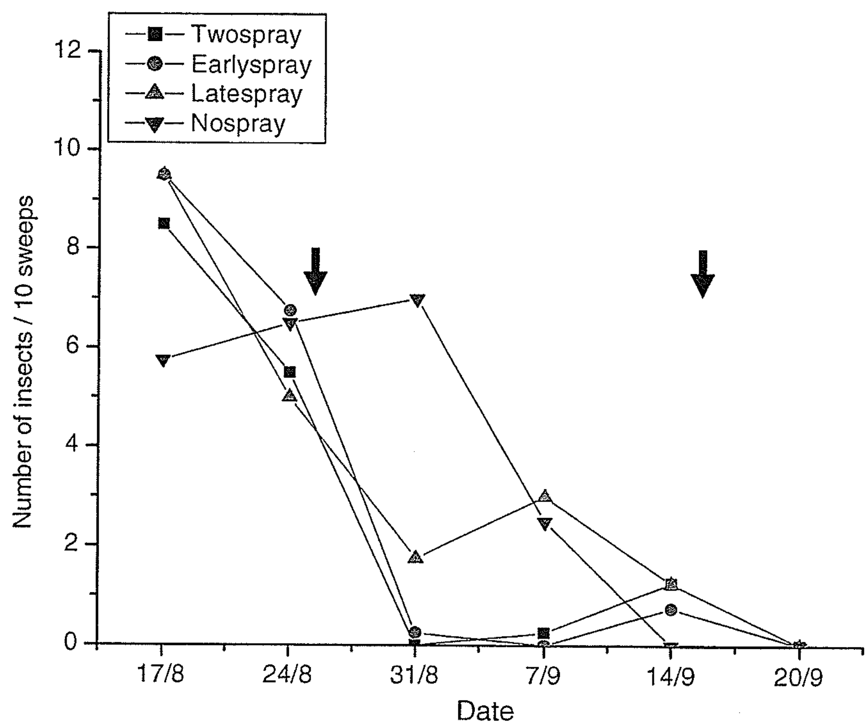
Fig. 30: Mean catches of *Adelphocoris* spp. adults (a) and nymphs (b) per 10 sweeps in seed alfalfa near Arborg, MB in 2004. Arrows denote the dates of the insecticide applications.

(a)



Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
1
2
3
4
5
6
7
8
9
10
11
12
17/8
24/8
31/8
7/9
14/9
20/9

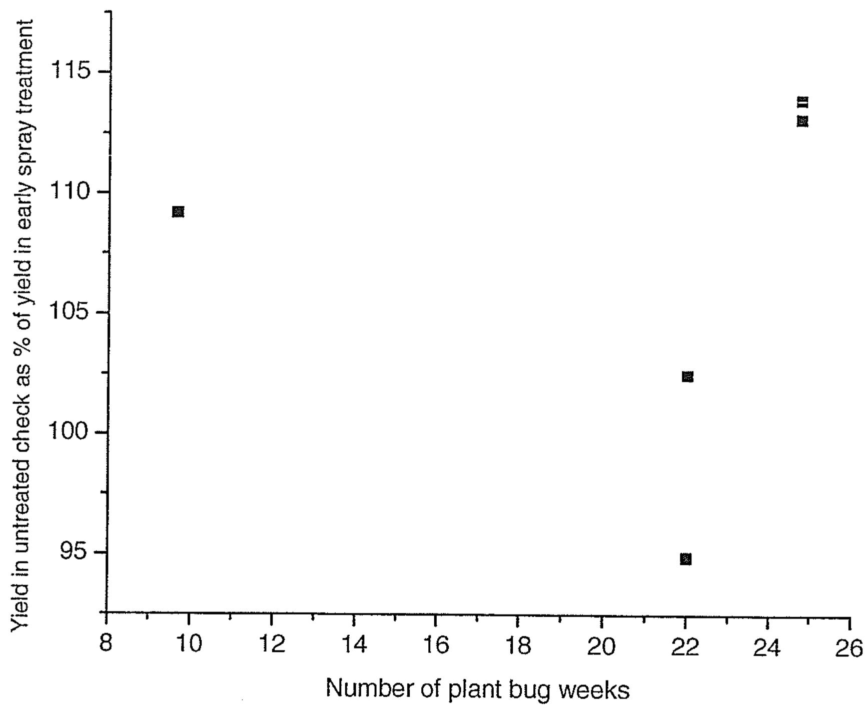
(b)



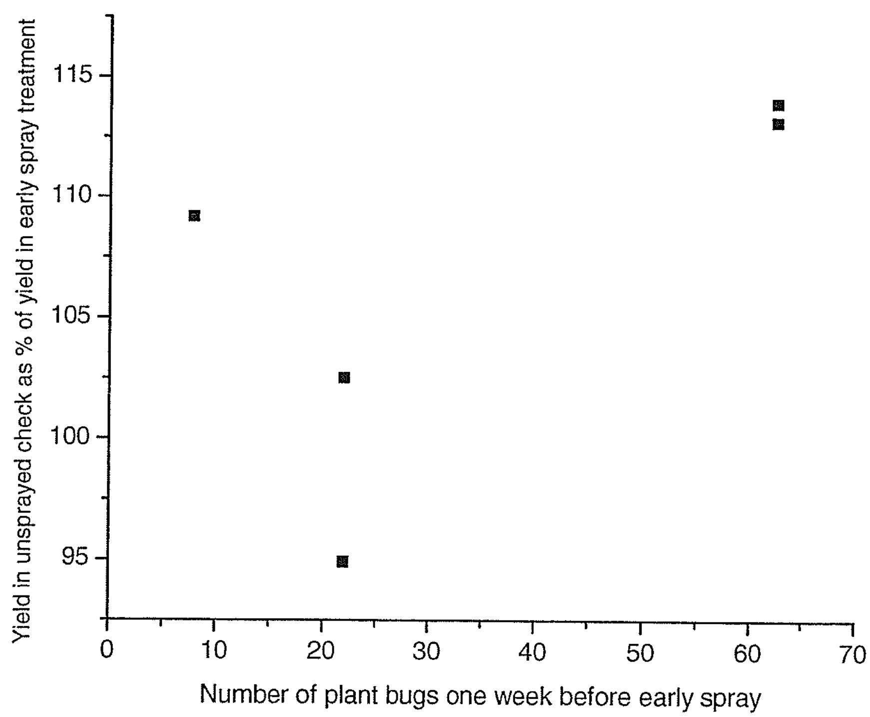
Twospray
Earlyspray
Latespray
Nospray
Number of insects / 10 sweeps
0
2
4
6
8
10
12
17/8
24/8
31/8
7/9
14/9
20/9
Date

Fig. 31: Yield in untreated check expressed as a percentage of the yield in the early spray treatment (a) in relation to plant bug weeks following the early application and (b) in relation to numbers of plant bugs in the week before the early insecticide treatment in three different trials. Only hand harvest has been used for 2002 trial, while hand and machine harvests have been used in 2003 and 2004 trials.

(a)


Yield in untreated check as % of yield in early spray treatment
115
110
105
100
95
8
10
12
14
16
18
20
22
24
26
Number of plant bug weeks

(b)


Yield in unsprayed check as % of yield in early spray treatment
115
110
105
100
95
0
10
20
30
40
50
60
70
Number of plant bugs one week before early spray

CHAPTER IV

General Discussion

The main objectives for this dissertation were to investigate the occurrence and effects of mirid plant bugs on buckwheat and seed alfalfa crops in southern Manitoba, particularly the effect of high late-season populations of adult plant bugs. I expected that plant bugs would show the same pattern of occurrence as in other crops and have economic effects on the yield parameters of both crops. Between expectations and actual results, this research came as another chapter in the long story of the interaction between plant bugs and their host crops.

I found that the tarnished plant bug, *L. lineolaris*, is almost the only mirid species in buckwheat, and it is becoming more dominant within the assemblage of lygus bug species in alfalfa in Manitoba. These results are in accord with previous studies in the same region (Timlick et al. 1993; Gerber and Wise 1995; Carcamo 2002). This species exhibited the ability to produce two generations relatively far north in Manitoba's agricultural area including the Interlake region. Increasing canola acreage and the further establishment of more alfalfa in southern Manitoba may be factors that favor the dominance of *L. lineolaris*. It is important to study the biology and occurrence of this insect in southern Manitoba in different crops and regions.

Dispersal of lygus bugs is a complicated issue. The current results showed that canola could be a source of the late season lygus bug adult population that appears in buckwheat and other crops. However, the numbers of these bugs in canola plots at Carman Field Station did not support the notion that canola is the only source of dispersing lygus bugs late in the growing season in southern Manitoba. Swathed alfalfa for hay may also be a source of dispersing lygus bugs (Schaber et al. 1990b), and forage alfalfa, seed alfalfa and weeds were sources for *L. hesperus* entering nearby cotton fields when the distances did not exceed 375, 1500 and 500 m for forage alfalfa, seed alfalfa and weeds, respectively (Carrière et al. 2006). Similar or smaller distances were found between canola fields, as sources of lygus bugs, and buckwheat and seed alfalfa, as recipient crops, during this study. Further investigation of the dispersal and the source of these lygus bugs is required. Different techniques may be used to follow the movement of this insect, such as mark-recapture using albumin marking and radiation marking.

As with most of their host plants, effects of plant bugs on yield of buckwheat and seed alfalfa are associated with the growth stage of the host plant and the population structure of the plant bug populations. In buckwheat, lygus bug nymphs synchronized with the flower stage may cause damage unless insecticide is applied at this time. Late season populations seem to have no significant effect on buckwheat and alfalfa within the range of numbers experienced during this study. However, if populations rise or the season becomes longer the situation could change. For seed alfalfa, the current levels of late season plant bug populations have no impact on the yield quality and quantity. However, it was suggested that higher populations, 12 bugs per sweep (Harris 1992), can cause economic yield loss. Similarly, in buckwheat, if first frost and subsequent harvest are delayed considerably from that observed in my study, the feeding by lygus bugs in early September may have greater effects on yield. Scouting for plant bugs and observing any feeding or damage symptoms are important, especially if conditions favour a longer growing season.

Several techniques have been used to study the response of plants to insect injury. The most common categories of these techniques are observation of natural insect populations, modification of natural populations, establishment of artificial populations and simulation of injury (Pedigo 2002). Modification of natural populations by using insecticide was the technique that was used in both buckwheat and alfalfa plots, and additionally, establishment of artificial populations in cages was used in buckwheat.

Using insecticide to manipulate insect populations can present some problems, mainly the unevenness of the effect of application on insect populations due to many factors, such as drift and variable vegetative canopy cover (Pedigo 2002). Caging plants creates a different environment than the natural one, particularly by increasing humidity and affecting the pattern of plant growth. Such effects can lead to different results in cages from those obtained in open field studies (Pedigo 2002). In my study, cage studies were used mostly to complement and elucidate open field studies and in buckwheat results of large cages and field studies corresponded closely.

At the beginning of this research, the population of lygus bugs on buckwheat late in the season, during late August and September, was of more concern because of the large numbers of insect observed then. However, nymphs developing during flowering had by far the most influential effect on buckwheat yield in five insecticide trials over three years and in two years of large cage studies. The late season lygus bugs, which were mostly adults, did not show any consistent effects on buckwheat yield despite their large numbers, except in the caged trial at Carman Field Station when lygus bugs were confined to the apical part of buckwheat in late August and September; those adults reduced seed weight and seed number and increased the percentage of malformed seeds. These late season effects on buckwheat yield in the apical cages required relatively high numbers of insects, and may have been accentuated artificially because of the restriction of the insects to a small portion of the plant. This assumption of a possible yield loss due to probable large population of late season lygus bugs was the motivation behind investigating the capability of the mycoinsecticide, Botanigard, to control late season populations. The inconsistent results with this product may partly be an indication of the lack of strong effects of natural populations of lygus bugs on buckwheat late in the season.

It was clear that the buckwheat plant is very vulnerable during the flowering stage, and the seed can be affected during the green seed stage, but no obvious effects were detected during the seed ripening stage. The late season population had no effect on buckwheat yield. However, a question still remains: what if the late-seaon population of lygus bugs is higher than that observed during the current study, and this was accompanied by a prolonged growing season with late harvest? It is possible that yield could then be influenced by late season populations.

In alfalfa, no effects of the late August insecticide application were detected. This led to the conclusion that the late growing season populations of plant bugs at the densities experienced recently in Manitoba have no effect on seed yield. Mirid plant bugs are known to affect seed and hay yield when attacking the early reproductive tissues such as buds, flowers and green pods and seeds. With the progress of plant maturation, the seeds and pods have hardened and are unsuitable for the insects' feeding (Hughes 1943; Gupta et al. 1980).

Higher populations of plants bugs late in the growing season may stress plants, especially in long seasons, and then cause yield effects. A cage study such as the one carried out for buckwheat plants, but under more realistic field conditions, could be used to study higher than normal late season populations, and if plants were protected from frost, could explore what would happen in exceptionally long growing seasons. Results from the study would have to be expressed as number of insects per sweep to allow for any derived thresholds to be applied. A similar study could also be used on alfalfa to examine whether late plant bug populations influence winter survival or growth in the following year.

Many similarities and some differences become apparent when comparing the effects of mirid plant bugs on buckwheat and seed alfalfa. The main effects of mirid plant bugs on yield of both crops arise from the feeding of the early season population, which consists of larger numbers of nymphs than adults. This population of nymphs is synchronized with the presence of reproductive plant tissues that are preferred by these insects, i.e. floral buds, flowers, green pods and green seeds (Hughes 1943; Gupta et al. 1980). Nymphs are more frequently found on these tissues of the plant than are the adults (Snodgrass 1993). By the end of the growing season, the plant reproductive tissues are tougher and unsuitable for feeding by bugs and the population consists mostly of adults. Adults are more mobile (Cleveland 1982; Snodgrass et al. 1984a & b; Fleischer and Gaylor 1987; Otani 2000) and in August and September in southern Manitoba they are nearing the end of the growing season. They probably respond to the short day length by seeking overwintering sites and entering reproductive diapause (Otani 2000). Therefore, only under exceptional circumstances, it appears, do late season populations produce an effect on the yield of buckwheat or seed alfalfa.

In buckwheat, lygus bugs were not observed on the plant before the first blooming of floral buds (personal observation), suggesting that they cause all or some of the same five categories of plant injury as described for other hosts (Tingey and Pillemer 1977). In alfalfa, as the season progresses, seed and pods become harder and the feeding of plant bug adults and nymphs has less effect on the plant. In contrast, buckwheat continues flowering until killed by frost, giving more opportunity for the lygus bugs to continue feeding on the vulnerable reproductive tissues. But this seems to have no effect on yield, perhaps because these flowers, and even green seeds, do not contribute to yield once 75% maturity has been attained (Manitoba Buckwheat Growers Association 1998).

When comparing the effects of plant bugs on seed alfalfa and buckwheat plants to other systems, canola and sunflowers appear to be comparable examples. Canola is comparable to seed alfalfa in that both plants produce flowers at a specific time and the seeds are confined within pods. Canola can tolerate more lygus bug infestation after forming the pod and seed hardening as indicated by the increase of the economic threshold from 15 lygus bugs per 10 sweeps at the flowering stage to 52 lygus bugs per 10 sweeps at the early pod stage (Wise and Lamb 1998b). This finding is similar to the current study on the late season population in seed alfalfa. The pod can protect the seeds, and with the hardening of the seeds, they become more tolerant to the infestation. The pattern of continuous flowering until frost and the naked seeds of buckwheat make the plant vulnerable to the lygus bug infestation. A similar system can be found in confectionary sunflower plants. The flowers are exposed and flowering is continuous as in buckwheat making them vulnerable to lygus bug feeding. Furthermore, confectionary sunflower growers cannot accept noticeable damage to their seeds (Charlet 2003). Similar to buckwheat, nymphs are responsible for most of the damage, furthermore the threshold is low, 1 adult / 10-15 plants (Charlet 2003).

The possibility that a much higher population of plant bugs later in the growing season could produce an effect on the yield of alfalfa and buckwheat may require further investigation. Manipulation of the insect numbers by using cages may be appropriate, although there may be problems with pollination and typical plant and insect responses in cages. Another problem is the transformation of the density inside the cage to a number that can be used by the grower, e.g. a number per sweep.

While there is an economic threshold for plant bugs in seed alfalfa early in the growing season (Manitoba Agriculture, Food and Rural Initiatives, 2005b), it was not possible to construct an economic injury level for buckwheat early in the growing season because of the high vulnerability of the crop to the lygus bug infestation at this time.

Sweep net sampling is the most commonly used method to scout for plant bugs, although the efficiency of this method is low especially for catching younger stages (Snodgrass 1993; Uddin 2005). Drop cloth sampling (Sndograss 1993), or similar methods like beat tray (Uddin 2005) or pot saucer sampling (Schaefers 1980) can provide better estimates for lygus bug nymphs that might lead to a more reliable economic injury level for lygus bugs on buckwheat. However, sweep net sampling is the most consistent and reliable method of sampling insects on some crops such as cotton (Snodgrass 1993), canola (Wise and Lamb 1998) and alfalfa (Uddin 2005).

The current study clearly demonstrated that the interaction between plant bugs and their host depends mostly on the host plant stage rather than the pest number. Numerous populations of plant bugs late in the growing season coincideding with the loweeast vulnerable plant growth stage in both buckwheat and seed alfalfa resulted in no or minor little or no effect on the crop yield. The rather smaller population numbers earlier in the season synchronized with the most vulnerable host stage affected the crop yield significantly. The plant bugs showed a very strong relation with the reproductive tissues of the host plant, especially floral buds and flowers, which cause both the expected and the surprise outcomes of this study.

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Appendix I: Monthly mean temperature (°C) and total precipitation (mm) at different experimental locations in Manitoba from May to September, 2002-2004.

Month	Weather data	2002			2003		2004
		Carman	Gimli[1]	Arborg	Carman[2]	Arborg[3]	Arborg
May	Maximum temperature	15.8	14.9	14.5	19.7	20.3	12.4
	Minimum temperature	0.5	0.2	-0.5	4.8	3.5	-0.3
	Mean temperature	8.2	7.6	7.0	12.3	11.9	6.1
	Total precipitation	40.8	45.8	32.2	80.2	20.2	72.6
June	Maximum temperature	23.5	23.6	23.0	22.4	23.6	19.0
	Minimum temperature	11.9	11.1	10.8	10.8	9.1	7.3
	Mean temperature	17.8	17.4	16.9	16.6	16.4	13.2
	Total precipitation	141.0	79.9	32.0	81.0	98.2	48.8
July	Maximum temperature	27.1	26.9	26.5	25.4	25.4	23.5
	Minimum temperature	13.5	13.8	13.7	12.9	12.2	10.6
	Mean temperature	20.3	20.4	20.1	19.2	18.8	17.1
	Total precipitation	49.4	79.6	98.2	56.4	37.4	50.0
August	Maximum temperature	24.0	24.1	23.4	27.8	27.9	19.4
	Minimum temperature	11.6	12.0	11.3	13.5	13.3	7.5
	Mean temperature	17.8	18.1	17.4	20.7	20.6	13.5
	Total precipitation	129.2	85.2	76.2	70.8	57.8	67.4
September	Maximum temperature	20.0	19.3	18.3	18.4	17.1	18.9
	Minimum temperature	7.3	7.2	6.2	6.4	6.1	8.0
	Mean temperature	13.7	13.3	12.3	12.4	11.6	13.5
	Total precipitation	21.0	49.6	36.8	36.2	86.2	70.6

[1] No data from Teulon were available, therefore, data from Gimli, which is about 30 km from Teulon, were considered.
[2] No data from Altamont were available, therefore, data from the University of Manitoba Carman Field Station, which is about 40 km from Altamont, were considered.
[3] No data from Riverton were available; therefore, data from Arborg, which is about 20 km from Riverton, were considered.