

THE UNIVERSITY OF MANITOBA

THE BIOLOGY OF LYGUS SPP. (HETEROPTERA: MIRIDAE)
ON OILSEED RAPE IN MANITOBA

BY

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JOHANNES H.M. LEFERINK

A Thesis submitted to the Faculty of Graduate Studies of the University of Manitoba in
partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

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ABSTRACT

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The biology of Lygus spp. (Heteroptera: Miridae) on oilseed rape in Manitoba. Major Professor: Dr. George H. Gerber.

The seasonal development of species of Lygus Hahn was studied on oilseed rape (Brassica napus L.) in the field and laboratory in Manitoba. In the field experiments, four seedings of oilseed rape (cv. Westar) were made at regular time intervals in 1988 and 1989 at Glenlea, Manitoba. The experiment was conducted in four replicate plots in 1988 and five in 1989, with each plot measuring 5 by 20 m.

The species composition of the lygus bugs was determined. Lygus lineolaris (Palisot de Beauvois) accounted for 82.9 and 55.2% of the adult lygus bugs on oilseed rape in 1988 and 1989, respectively. Lygus desertinus Knight and L. borealis (Kelton) together accounted for 17.1% of the adult lygus bugs in 1988 and for 7.7 and 37.1%, respectively, in 1989. Rearing of the nymphs resulted in adults of all three species, which indicated that all three species reproduced on this crop. Adult lygus bugs first appeared on oilseed rape at the beginning of flowering stage. Nymphs appeared from 1 to 3 weeks later. Peak abundances and median of the nymphal instars and peak abundances and timing of median of the new adults occurred during the pod development stages. New adults of L. desertinus usually reached median and peak abundances earlier than L. borealis.

The median of L. desertinus was from 8.2 days earlier to 0.2 days later than that of L. borealis, and from 6.5 days earlier to 1.6 days later than that of L. lineolaris. The peak of L. desertinus was from 3 to 10 days earlier than that of L. borealis and L. lineolaris.

The effect of temperature on the rate of development of L. lineolaris was determined in the laboratory. Lygus lineolaris was reared from egg hatching to the adult stage at five different temperatures ranging from 15.6° to 22.1°C. All rearing was at 80±5% R.H., and 16 h L : 8 h D photoperiod. The relation between temperature and rate of development of each nymphal instar was linear. Developmental time was negatively related to temperature: at 22.1°C the average time for development was 19.6 (SD = 1.3) days and at 15.5°C it was 41.8 (SD = 1.9) days. Threshold temperatures for development were estimated at 6.1, 8.3, 9.8, 10.7, and 11.4°C for the first, second, third, fourth, and fifth nymphal instar, respectively.

The daily average air temperatures in the field were used as a parameter to estimate the expected times for development of L. lineolaris in the field in 1988 and 1989. The starting point for the estimated developmental times was the observed time of the median of the first nymphal instar. The observed times of the median of the adult stage were from 0.4 later to 22.3 days earlier than the expected times during the two years.

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1 INTRODUCTION

1.1 Pest Status of Lygus Bugs

The genus Lygus Hahn (Miridae: Heteroptera) comprises a group of plant bugs which feed on a wide diversity of plant species. Lygus bugs tend to occur as a complex of several species. In this thesis, Lygus spp. will be referred to as "lygus bugs". The genus includes important pests of seed, fruit, and nursery crops throughout North America, Asia, and Europe. Currently, 43 species of lygus bugs are recognized worldwide and 34 species occur in North America (Kelton 1975). At least nine species are of economic importance to agriculture in North America (Kelton 1975).

Losses due to lygus bug feeding are extensive in a geographical, economical, and agronomical sense. Over 130 crops grown in North America receive some economic damage due to lygus bugs (Young 1986). Many farmers and pest control operators consider lygus bug damage important enough to warrant control.

Oilseed rape (Brassica napus L. and B. campestris L.) has many insect pests (Lamb 1989). However, only a few of those pests require control in Manitoba (Bracken 1987; Lamb and Turnock 1982). Lygus bugs frequently are present in oilseed rape fields. Surveys of oilseed rape fields in Manitoba for lygus bug damage were conducted from 1985 to 1989. Yearly field losses of seeds ranged from 11.7% to 17.7% (Turnock et al. 1989). Lygus bugs, therefore, appear to be serious economic pests of oilseed rape in this province.

Lygus bugs are polyphagous, but they feed specifically on meristematic and developing reproductive plant tissues (Tingey and Pillemer 1977). Damage to flowers, fruits, and seeds is a typical consequence of lygus bug feeding. Damage results from the combined

effects of destroyed plant tissue, physiological reactions of plant tissue to feeding, and the mechanical action of feeding. This damage results in shedding, malformation, or abortion of plant structures such as flowers and young fruit (Tingey and Pillemer 1977). The severe effects of feeding and the specific feeding site preferences of lygus bugs lead to considerable economic damage at lower densities than generally is the case for insect pests (Mailloux and Bostanian 1988; Tugwell et al. 1976).

Lygus bugs have been studied extensively. Graham et al. (1984) published a bibliography of the world-wide literature of lygus bugs from 1900 to 1980, which contains over 2400 references. Only a few studies have originated from the Canadian prairie provinces. They dealt with lygus bugs on alfalfa (Medicago sativa L.) in Alberta and Saskatchewan (Craig 1983; Salt 1945). A more recent study dealt with lygus bugs in oilseed rape in Alberta (Butts 1989). There are no studies in the scientific literature concerning lygus bugs in Manitoba. The study by Butts (1989) focused on lygus bug population development on oilseed rape and on the effects of glucosinolate content on the ability of lygus bugs to exploit oilseed rape as a host. The current study deals with the seasonal development of nymph and adult lygus bug populations on the oilseed rape cultivar Westar (B. napus) in Manitoba.

1.2 Objectives of the Study

The present study was undertaken to obtain a comprehensive picture of the development of lygus bug populations on oilseed rape (B. napus cv. Westar) in southern Manitoba. The aims of the study were as follows:

1. To determine the time of colonization of lygus bugs in relation to the stages of oilseed rape development.

2. To describe the development of populations of nymphs and adult lygus bugs in relation to the stages of development of oilseed rape.
3. To determine the relationship between temperature and rate of development of field populations of lygus bugs on oilseed rape.
4. To determine the species composition of the lygus bug assemblage.

The information obtained from this study will be utilized in formulating a pest management system for lygus bugs on oilseed rape. The study is a part of a research programme which is being conducted by the Crop and Stored Product Pests Section, Research Station, Agriculture Canada, Winnipeg, on lygus bugs on oilseed rape.

1.3 Thesis Organisation

The thesis is divided into five major sections: Introduction, Literature Review, Methods, Results, and Discussion. The Literature Review provides information on the biology of lygus bugs, and focuses on the relationships between lygus bugs and their host plants. In the Methods, Results, and Discussion, the original thesis research is described and discussed.

2 LITERATURE REVIEW

2.1 Species Composition of Lygus

Lygus bugs occur in most areas of North America where agriculture is conducted (Kelton 1975). In this thesis, only the species which are recorded as pests are discussed. Only Lygus lineolaris (Palisot de Beauvois) has a continent-wide distribution. It is the dominant species east of the Rocky Mountains (Kelton 1975). Lygus hesperus Knight and L. elisus van Duzee are the dominant species west of the Rocky Mountains. The other lygus bug species have less extensive ranges. In the prairie provinces of Canada, there are 22 lygus bug species, of which 14 occur in Manitoba (Kelton 1980). Lygus desertinus Knight, which is predominantly a western species, has been collected in Manitoba (Kelton 1975). Lygus borealis (Kelton) has a northwestern distribution, which includes Manitoba (Kelton 1975).

Lygus bug species distributions tend to overlap in many areas (Kelton 1975). The relative abundance of specific species varies among locations and even on the same host at different localities. For example, in Saskatchewan, the relative abundance of species differs significantly from area to area on alfalfa (Craig 1983). At Moose Jaw, in the short grass prairie region, the species composition is 84% L. borealis, 13% L. desertinus, and 3% L. lineolaris. At Saskatoon, in the mixed prairie region, the species composition is 64% L. borealis, 30% L. lineolaris, and 6% L. desertinus. At Torch River, in the forested region, the species composition is 43% L. unctuosus (Kelton), 39% L. borealis, and 18% L. lineolaris.

The composition of species of lygus bugs invading crops is influenced by the species composition of lygus bug assemblages on

surrounding weeds or crops (Fye 1982b; Malcolm 1953; Stitt 1940). Host plants may favor the development of some lygus bug species over others. Fye (1982b) found that on early flowering crucifers L. elisus is the dominant species in central Washington. This species is also dominant on Chenopodiaceae, especially Chenopodium murale L., which flowers later in the season. Lygus hesperus, on the other hand, predominates on alfalfa.

Growth stage of a host species may also affect lygus bug species composition. Fye (1982b) found that L. elisus is more abundant on alfalfa at the vegetative stage and L. hesperus is more abundant at the reproductive stages.

2.2 Life History

Lygus bugs overwinter in the adult stage. Most other mirids overwinter in the egg stage (Kelton 1980). Overwintering of lygus bugs occurs under plant litter at the edges of fields, forests, streams, and roads (Crosby and Leonard 1914). Winter survival rate is positively correlated with moisture content of overwintering sites (Fye 1982a; Landis and Fox 1972). In experimental studies, no lygus bugs survived the winter when their hibernation site contains less than 10% moisture; however by adding moisture, survival doubles with each increment of 20% up to 80% moisture content of dry weight (Fye 1982a). During winter, when temperatures are above zero, lygus bugs may be active from time to time (Fye 1982a; Stitt 1940; Wheeler 1974). Overwintered lygus bugs emerge from their hibernation sites early in spring as soon as temperatures reach 10°C or higher (Fye 1982a; Landis and Fox 1972).

Soon after emergence, reproductive activity starts in lygus bugs. They mate more than once during their life time (Bariola 1969; Strong 1971). The total number of eggs produced by L. lineolaris under

laboratory conditions ranges from 31 to 183 (average 98.7) (Bariola 1969). Individual egg production may vary greatly under different host and environmental conditions (Cave and Gutierrez 1983; Strong et al. 1970). Eggs are deposited inside plant tissue so that the operculum is flush with the plant surface (Painter 1927). They occur singly or in loosely arranged aggregates of up to eight. Eggs are deposited on most hosts visited (Al-Munschi et al. 1982).

Incubation time of eggs ranges from 6 to 18 days and is inversely related to temperature (Bariola 1969; Khattat and Stewart 1977). Emerging nymphs are small and greenish in color. They feed on the same plant structures as adults. They pass through five nymphal instars before reaching the adult stage (Kelton 1975). Nymphs are very agile, and thus able to move very readily to new resources on or in the vicinity of their host. However, as they do not possess wings, migration to other hosts is limited.

As the growing season progresses, the number of overwintered adult lygus bugs in the field gradually decreases (Kelton 1975). By the last week of June or the first week of July in Canada, the lygus bug population consists almost exclusively of first generation adults, the offspring of the overwintered adults.

Reproductive activity stops in late summer in Canada and the northern parts of the United States (Craig 1983; Ridgway and Gyrisco 1960b; Salt 1945). Feeding continues on the available succulent host plants. During this time, a large fat body is formed. Lygus bugs go into hibernation soon after the first frosts.

The number of generations per year of lygus bugs depends mainly on the length of the growing season and on the mean temperature. At Torch River, Saskatchewan, there is only one generation per season. At Moose Jaw, lygus bug populations are bivoltine (Craig 1983). At Ithaca, New York, three generations are found (Ridgway and Gyrisco

1960b). In Louisiana, there are four or more generations per season (Anderson and Schuster 1983).

2.3 Host Plant Utilization by Lygus Bugs

Most adults feed and reproduce on a series of hosts during the growing season (Anderson and Schuster 1983; Cleveland 1982; Domek and Scott 1985; Fleischer and Gaylor 1987; Fye 1982b). After emergence in spring, overwintered lygus bugs move to and feed on the buds of trees and shrubs, such as willow (Salix spp.) and apple (Pyrus malus L.) (Crosby and Leonard 1914). Soon after, they move on to newly emerged herbs. Feeding and reproduction takes place on herbaceous plants during the rest of the growing season.

2.3.1 Host Plants

Lygus bugs are generalist herbivores (Prokopy and Owens 1983). Most species feed on a considerable number of plant species belonging to a variety of families. The majority of host species are herbaceous dicotyledons. Except for a few incidental records, no monocotyledons are hosts to lygus bugs in North America (Young 1986). Lygus lineolaris feeds and (or) reproduces on more than 360 host species in 55 plant families (Taksdal 1963; Young 1986). Lygus hesperus has been recorded from over 100 species in 24 families (Domek and Scott 1985, Scott 1977). Cruciferous plants are among the known hosts for lygus bugs. The list includes turnips (Brassica rapa L.), oilseed rape, wild radish (Raphanus raphanistrum L.), wild mustard (Sinapis arvensis L.), and perennial pepperweed (Lepidium latifolium L.) (Butts 1989; Crosby and Leonard 1914; Fye 1982b; Snodgrass et al. 1984).

2.3.2 Host Plant Colonization

Lygus bugs show a great ability to fly and colonize suitable hosts (Boivin and Stewart 1983b; Fleischer et al. 1988; Mueller and Stern 1973). Factors governing flight activity and host plant selection behavior, therefore are important in host colonization and in the pest status of lygus bugs.

2.3.2.1 Flight Activity

Most evidence for inter plant movements of lygus bugs have been inferred from concurrent changes in population densities among different host plants (Fleischer et al. 1988). In southern California, sudden increases of lygus bug abundance in cotton fields usually follow equally sudden decreases in abundance in recently harvested safflower fields (Carthamus tinctorius L.) (Mueller and Stern 1974).

Lygus bugs fly in random directions before encountering potential hosts (Fleischer and Gaylor 1988). Mueller and Stern (1973) found no correlation between direction of flight and prevailing wind.

The potential range of flight of lygus bugs is extensive. Flight distances of up to 4 km have been reported (MacCreary 1965). Peak flight activity of lygus bugs occurs during dusk (Butler 1972; Fleischer and Gaylor 1988; Mueller and Stern 1973; Strong et al. 1970). Using sticky traps, it was found that 90% of the L. lineolaris fly at a height of less than 1.8 m and 70% fly at a height of less than 1.0 m (Ridgway and Gyrisco 1960b). Similar observations were made for L. hesperus and L. elisus (Mueller and Stern 1973). Low level flight has two main advantages for lygus bugs: they are flying in an air zone with generally low wind velocities, and most of the generative structures of the hosts plants are located at these heights.

Quality of available food strongly influences flight activity in insects (Johnson 1969). Deterioration of quality of host plants induces emigration of lygus bugs (Cleveland 1982; Fleischer and Gaylor 1988; Stern et al. 1964). Mueller and Stern (1974) noted that lygus bugs will stay on irrigated alfalfa as long as the crop does not suffer water stress. Emigration of lygus bugs also can result from harvesting of crops and mowing of weeds (Cleveland 1982; Fleischer and Gaylor 1988; Stern et al. 1964). With harvesting and mowing, crop and weed hosts either are not available any more to lygus bugs because they were removed in the process, or host quality deteriorates as a result of decreases in moisture content and nutrients, because the plants were left on the field to dry. Water and nitrogenous compounds are critical components of lygus bug diets (Butler 1968; Cohen 1982).

2.3.2.2 Aspects of Host Plant Selection

As in most insects, the process of host plant selection in lygus bugs is governed by the combined responses to chemical (Tingey and Pillemer 1977) and visual stimuli (Ave et al. 1978; Hatfield et al. 1982; Hatfield et al. 1983). Host selection behavior affects alighting, feeding, and oviposition of lygus bugs on host plants.

As lygus bugs are closing in on a potential host plant, cues from the host start to affect their flight direction. Visual cues seem to play a role here (Landis and Fox 1972; Prokopy et al. 1979). Significantly more L. lineolaris are captured on white and gray than on green, yellow, red, black, or aluminium rectangles. However, captures on clear Plexiglas are as great or greater than captures on pigmented rectangles approximating the spectral reflectance pattern of buds, blossoms, foliage, or bark (Prokopy et al. 1979). Plant structures such as buds and blossoms are visited more often than leaves, twigs, or

trunks; however, there is no difference among numbers of visits to imitations, in shape and color, of these plant structures (Prokopy and Owens 1978). Therefore, it is not clear what roles color or shape play in host plant selection.

Olfactory cues also are involved in flight orientation towards host plants (Hatfield et al. 1983; Hatfield et al. 1982). Results from a field study suggested that L. lineolaris adults showed directional movement toward Erigeron annuus (L.) (Fleischer et al. 1988).

On contact with host plants, a series of behaviors is followed by the lygus bug. First, locomotion is arrested for a moment (Ave et al. 1978). Then, the lygus bug moves around on the plant tapping with its antennae. Motion is then arrested, and the rostrum is tapped on the plant surface. It probes by inserting its stylets into the plant tissue (Hatfield et al. 1983). At this stage, salivation and reingestion of salivated material occurs (Flemion et al. 1952).

Quantitative aspects of feeding behavior differ among host plants (Hatfield et al. 1983). Lygus lineolaris spends more time feeding than non-locomotion, locomotion, tapping, or probing on mustard, alfalfa, and cotton plants. Significantly more time is spent feeding on mustard than on alfalfa or cotton.

The acceptability of a feeding site is tested with the rostral chemosensilla (Hatfield et al. 1982). Removal of rostral tip sensilla abolished feeding preference for frego bract, a type of cotton very susceptible to lygus bug attacks, over normal cotton (Hatfield et al. 1982). Gossypol is a feeding deterrent in cotton (Purseglove 1968). Rostral probing allows lygus bugs to feed on cotton by avoiding gossypol-containing leaf glands (Cota 1980). Epipharyngeal chemosensillary input modifies the ingestion of incitants and feeding deterrents (Hatfield et al. 1982). Sugar is a feeding stimulant, and the amount of a sugar solution ingested was positively related to its

concentration (Hatfield et al. 1983). Evidence suggests that moisture also is an important feeding stimulant (Curtis and McCoy 1964).

Although oviposition takes place on most plants lygus bugs feed on (Cleveland 1982), there are large differences in oviposition preferences. They are mainly due to host plant species and condition. However, lygus bugs do not always lay eggs on the most suitable host for their nymphs (Curtis and McCoy 1964; Elmore 1955; Graham and Jackson 1982; Shull 1933).

Differences in host preference for oviposition have been noted among and within plant species (Benedict et al. 1981; Bosque-Perez et al. 1982). In some situations, lygus bugs oviposit on plant species they normally avoid. When herbaceous hosts such as Senecio vulgaris L. or Sanguina procumbens L. are not available, lygus bugs lay their eggs on Norway spruce seedlings (Picea abies (L.) Karst) (Holopainen 1989).

Host plants with flowers and buds are preferred for oviposition over other growth stages (Alvarado-Rodriguez et al. 1986; Wilson and Olson 1990). High moisture content in plant tissues incites oviposition as well (Curtis and McCoy 1964; Graham and Jackson 1982). However, secondary plant chemicals may have a limited effect on oviposition preference. Glandless cotton, which does not contain the repellent gossypol, does not differ in oviposition preference over varieties with such glands (Benedict et al. 1981; Tingey et al. 1975).

The physical nature of a potential host also may be a factor in oviposition (Benedict et al. 1983). The surface structures of the host are important. Increased trichome density on cotton decreases oviposition by 40 to 60% in no choice tests (Benedict et al. 1983). Host plant height is positively correlated with oviposition preference (Tingey and Leigh 1974).

2.3.3 Population Development

Although lygus bug populations occur on a considerable number of host plants at any one time, differences in population density among host plants are often of such magnitude that key hosts can be recognized (Anderson and Schuster 1983; Cleveland 1982, Fleischer and Gaylor 1987). Host plants affect the generation of new adults through factors which determine egg production and nymphal development (Cave and Gutierrez 1983; Fleischer and Gaylor 1988). Temperature also plays an important role in population development of lygus bugs (Anderson and Schuster 1983; Fleischer and Gaylor 1988).

2.3.3.1 Egg Production

The total number of eggs produced and the age of the females at oviposition are important aspects in population development (Cave and Gutierrez 1983; Fleischer and Gaylor 1988). Factors determining total number of eggs produced are daily rate of egg production and longevity of the adults (Al-Munshi et al. 1982; Cave and Gutierrez 1983).

Total and daily egg production are determined, in large part, by the species of the host plant (Al-Munshi et al. 1982; Cave and Gutierrez 1983; Curtis and McCoy 1964). Lygus hesperus produces on average 49.7 eggs on cotton and only 39.6 eggs on alfalfa (Cave and Gutierrez 1983). Fleischer and Gaylor (1988) found egg production of L. lineolaris is significantly higher on cotton (138 eggs) than on E. annuus (87 eggs). However, average daily egg production is higher on E. annuus (3.36 eggs/day) than on cotton (2.20 eggs/day), because L. lineolaris lives for a shorter time on E. annuus than on cotton. Daily egg production of Lygus hesperus is fairly constant on alfalfa (Cave

and Gutierrez 1983). However, on cotton, about 80% of all eggs are produced early in the female's life. There is a similar pattern of peak egg production at an early age in L. lineolaris on E. annuus (Fleischer and Gaylor 1988). Higher daily egg production on E. annuus than on cotton, especially during the early ovipositional period, results in a higher intrinsic rate of increase on E. annuus (0.107) than on cotton (0.058) (Fleischer and Gaylor 1988).

The stage of development of the host plant also can affect egg production. Lygus lineolaris produces few eggs on a diet of cotton seedlings (Cave and Gutierrez 1983). Butler (1968) found that lygus bugs produce eggs on alfalfa only when it is flowering. Nitrogenous compounds in the diet are important for egg production. Reproductive parts of plants are relatively high in nitrogenous compounds, but leaves contain relatively little of these compounds (McNeill and Prestidge 1982).

2.3.3.2 Nymphal Development

Development of nymphal populations of lygus bugs is determined by growth rate and mortality (Cave and Gutierrez 1983; Fleischer and Gaylor 1988). Mortality and growth rates are affected by host plant species, variety, and temperature (Alvarado-Rodriguez et al. 1987; Benedict et al. 1983; Cave and Gutierrez 1983; Curtis and McCoy 1964).

Nymphal mortality rates differ significantly among host plants (Bariola 1969; Fleischer and Gaylor 1988; Khattat and Stewart 1977). On alfalfa, the mortality rate is 36% and on cotton, it is 68% (Cave and Gutierrez 1983). On some uncultivated herbaceous host plants, such as E. annuus, mortality rates are as low as 15% (Fleischer and Gaylor 1988).

Lygus bugs nymphs cope well with secondary plant metabolites.

Feeding deterrents, such as glucosinolates or gossypol, do not affect growth or mortality significantly (Butts 1989; Leigh et al. 1985). However, the absence of extra-floral nectaries in cotton results in a significant increase in nymphal mortality (Bailey et al. 1984). Extra-floral nectaries are a source of carbohydrates and amino acids for *Lygus* nymphs (Hanny and Elmore 1974).

Developmental times differs significantly on the host plants studied (Alvarado-Rodriguez et al. 1986; Benedict et al. 1983; Fleischer and Gaylor 1988). On 11 weed species, the developmental times from first nymphal instar to adult emergence of *L. lineolaris* ranged from 11.3 to 19.9 days at 26.5 °C (Fleischer and Gaylor 1988).

Lygus bug nymphs develop over a wide range of temperatures. The threshold temperature for nymphal development may vary. It ranges from 8.0 to 11.7 °C, depending on the host plant species (Bariola 1969; Fleischer and Gaylor 1988). The maximum temperature at which some development occurs is 34 °C (Fleischer and Gaylor 1988). At 19 °C, the development from first nymphal instar to adult emergence of *L. lineolaris* on *E. annuus* takes 24 days. At 22 and 26.5 °C, the developmental times are 17.5 and 14.5 days, respectively (Fleischer and Gaylor 1988).

3 METHODS AND MATERIALS

The present study consists of two parts: two field experiments and a laboratory experiment. In the field experiments, all four objectives for this study were addressed (section 1.2). The laboratory study investigated the relation between nymphal development and temperature under controlled conditions, and provided supplementary information for objective 3.

The two field experiments were conducted at the Field Station of the Agriculture Canada Research Station at Glenlea, Manitoba, during the field seasons of 1988 and 1989. They consisted of four treatments in the form of four seedings of oilseed rape (B. napus cv. Westar) (Fig. 1). In 1988, the seedings were on 3 May, 18 May, 1 June, and 18 June. In 1989, the seedings were on 9 May, 29 May, 6 June, and 16 June. Seeding 1 of 1989 started on day of first rains on 17 May, eight days after planting. This date is considered as the effective seeding date for that seeding. The experiment was set up as a randomized complete block design (Fig. 2). A strip around each plot, 2.4 m wide, was kept bare of vegetation to prevent migration of nymphs between plots. Buffers, 6 m wide, were kept free of plants around the experimental area to avoid other possible sources of lygus bugs. There were four and five replicates in 1988 and 1989, respectively.

The normal practices for seed bed preparation for oilseed rape were followed (Thomas 1984). A pre-plant application of trifluralin was incorporated into the soil to control weeds. Oilseed rape was seeded at a rate of 7 kg/ha at a depth of 2 cm. The seed had been pretreated with granular Furadan CR-10[®] (carbofuran) (0.280 kg a.i./ha) for control of flea beetles. The rows were 30 cm apart, double the commercial distance, because wider spacing between the rows made sampling easier.

The spring of 1988 was extremely dry. Immediately after the first seeding, and again on 13 June, the experimental area was irrigated with about 25 mm of water. This provided moisture for germination and initial growth of seedlings 1 and 2.

Plots were sampled regularly for nymphs and adults of lygus bugs with a sweep net. Sweep nets are commonly used to study lygus bug populations in field experiments (Butts 1989; Schotzko and O'Keefe 1989). Sweep nets had a bag diameter of 45 cm and a handle length of 75 cm. Each sweep consisted of a 90° stroke through the canopy of the crop, the bag frame going through a horizontal plane. The top of the bag frame barely touched the plant tops during each sweep. The sweep net handle was held with both hands and the right arm held straight. Sweep net samples were taken randomly in the plots. On each sampling day, the first plot to be sampled was randomly chosen. The rectangular shape of the plots allowed for most sweeps to be taken from the plot perimeter. Depending on weather conditions, each plot was sampled every third or fourth day, from the time the oilseed rape was in the fourth leaf stage until full maturity. Plots in seedling and early rosette stages were not sampled because the plants were too small and tender to be swept. Samples were taken on 18 days in 1988 and on 20 days in 1989. On each sampling day, one sample of ten sweep net strokes was taken per plot.

Lygus adults were identified to species using Kelton (1975) and counted. In the 1988 experiment, samples were analyzed in the field. In the 1989 experiment, the adults were preserved in a fixative containing formaldehyde (Weaver and Thomas 1956), and were identified in the laboratory using a dissecting microscope. Nymphs cannot directly be identified to species, because no keys are available. Therefore, for species determination, a number of nymphs were reared to adults. Nymphs were collected randomly with a sweep net from the plots

on 7 July 1988 and on 22 July 1989. They were reared on excised oilseed rape pods at $21 \pm 0.1^\circ\text{C}$, 80% R.H., and 16 h L : 8 h D. Petri dishes, 15 cm in diameter and 3 cm deep, were used as cages. Up to 10 nymphs were placed in each cage.

Species composition was compared among years, seedings, and sampling days within seedings. Estimates of species composition for years and seedings were obtained by pooling the counts of Lygus species occurring in the samples. As well, the mean frequencies of Lygus species among days were compared. χ^2 tests (SAS Institute 1990) were used to assess the degree of association among the Lygus species frequencies for years, and sampling days. F-tests were used to compare the average counts per sample by species among years. Differences among the average counts per sample of species within seedings were compared using the Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$, using square root transformed data (SAS Institute 1990). Development of lygus bug populations were compared with the development of oilseed rape using relative densities of adults of lygus bug species and nymphal instars on the different stages of oilseed rape. The growth stage (Harper and Berkenkamp 1975) of the oilseed rape in each plot was recorded at each sampling date.

The time of peak catch and the median time of catch were used to describe the development of the nymphal instars and adults as well as the species of adults. Medians were calculated (Sokal and Rohlf 1981), and differences among the times for catches of adults of the species were compared by Ryan-Einot-Gabriel-Welsch multiple range test at $\alpha = 0.05$ (SAS Institute 1990). The median of the adult stage was corrected for the adults moving into the crop during flowering by using only the samples collected during the pod development stages of oilseed rape. The medians for the nymphal instars were computed from the pooled data of all three species of lygus bugs, because the nymphs could not be

identified to species.

The laboratory experiment was conducted to determine the effect of temperature on the length of the developmental period of L. lineolaris from the first instar to the adult stage on oilseed rape. The results of this experiment were compared with the observations on development of lygus bugs in the field experiment. Lygus lineolaris was used, because it is the most abundant lygus bug species in oilseed rape in Manitoba (Turnock et al. 1989).

A stock colony of L. lineolaris was set up in the laboratory with adults collected from field populations on oilseed rape. The cages were cylindrical, clear plastic containers, 27 cm high and 17 cm in diameter, with fine mesh covered openings in the side and top. Potato sprouts and oilseed rape pods (c.v. Westar) were provided as food (Slaymaker and Tugwell 1982). Potato sprouts also served as oviposition sites. Freshly-sprouted potatoes were placed into the cages at about monthly intervals. A supply of oilseed rape pods was provided by growing oilseed rape in pots in the green house. Fresh pods were added to each cage every second or third day. The colony was kept in a controlled environment cabinet at 16 h L : 8 h D, $21 \pm 0.1^{\circ}\text{C}$, and 80% R.H..

Adults were taken from several stock colony cages and placed together on freshly sprouted potatoes in cages similar to the stock colony cages and under the same conditions as the colony. After 2 to 3 days, the adults were removed. The sprouts, which now contained eggs, were removed from the tubers and incubated in Petri dishes (15 by 2 cm) which had a fine mesh covered openings in the lid. The Petri dishes were then placed under the same conditions as the stock colonies in a controlled environment cabinet, and were checked daily for newly hatched nymphs.

First instar nymphs were removed from the containers within

24 h after emergence. The rearing cages for the nymphs were modified plastic Petri dishes, 10 cm diameter by 1.5 cm deep. To prevent condensation of water inside the cages, the lids were perforated by five small holes to enhance ventilation. The bottom of each rearing cage was covered with filter paper for absorption of free moisture. The rearing cages were placed in a controlled environment chamber (Fig. 3) at 16 h L : 8 h D, 80% R.H., and at a specific temperature. The temperature in the environment chamber was calibrated to give the desired treatment temperature inside the rearing cages. With the lights on, the temperature in the rearing cages was about 2°C higher than outside the cages. During the light period, the treatment temperature in the rearing cages was maintained by adjusting the temperature setting of the controlled environment chamber. Treatment temperatures were chosen to correspond to the mean monthly temperatures during the oilseed rape growing period. The temperatures were 15.6, 18.5, 19.4, 19.9, and 22.1±0.1°C. The mean monthly temperatures from May to August at Glenlea, Manitoba, are 11.4, 16.9, 19.6, and 18.3°C, respectively (Environment Canada 1983). Each rearing chamber received a maximum of five nymphs. Fresh, excised, oilseed rape pods (c.v. Westar; stages 5.1 to 5.2 (Harper and Berkenkamp 1975)) were placed in the rearing chambers every second day as food. During the experiment, each day at a specific time, the stage of development of each nymph was monitored. Adults were removed from the experiment soon after emergence. Experiments were terminated after the last nymphs had reached the adult stage.

The mean length of the developmental period from hatching to adult emergence was determined by adding up the mean times spent in each nymphal instar. The relationship between temperature and developmental rate of each nymphal instar, as percent development per day, was analysed using regression analysis (SAS Institute 1990).

Threshold temperatures were estimated from the linear functions where development rate reached zero. The linear functions and the threshold were used to estimate the degree days required for each instar to complete development (Campbell et al. 1974).

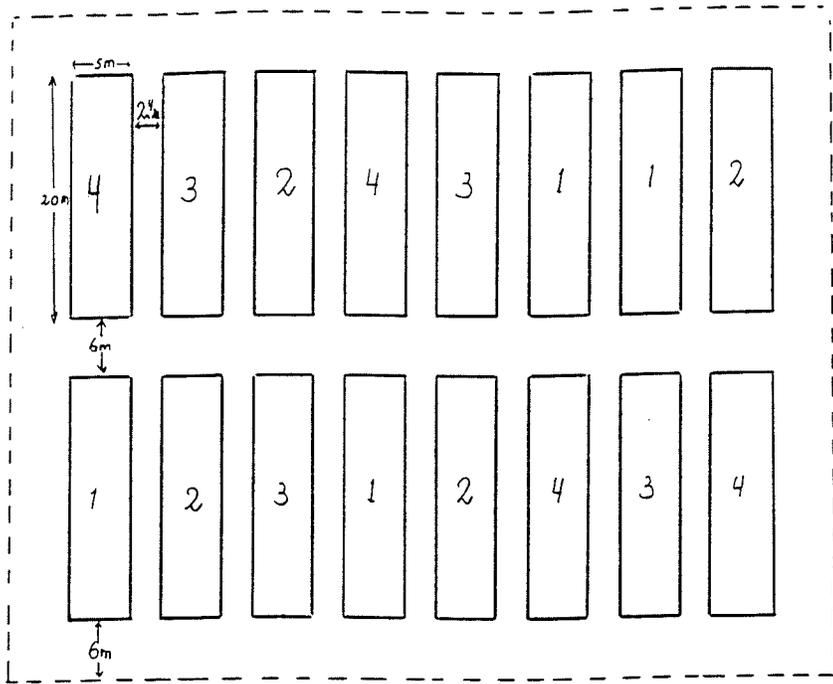
Degree days in the field were calculated from the daily minimum and maximum temperatures, obtained from the weather station at Glenlea (Monthly Climatological Message for Canadian Weather Review, Glenlea Research Station, 1988 and 1989), and the estimated threshold for each nymphal instar. Calculations of degree days were based on the Baskerville approximation of the sine curve (Baskerville and Emin 1969) using a computer program (Acts Degreedays, SCD Corporate Software Service).

Fig. 1. Field experiment at the Field Station of Agriculture
Canada Research Station at Glenlea, Manitoba, in late
July 1989. View from the south west corner of the
field.

Fig. 2. Layout of the field experiments in 1988 and 1989 at the Field Station of Canada Agriculture Research Station, Glenlea, Manitoba. Plots were laid out in a randomized complete block design. Numbers in plots correspond to the four seeding dates of oilseed rape (cv. Westar). The experiments consisted of four replicates in 1988 and five replicates in 1989.



1988



1989

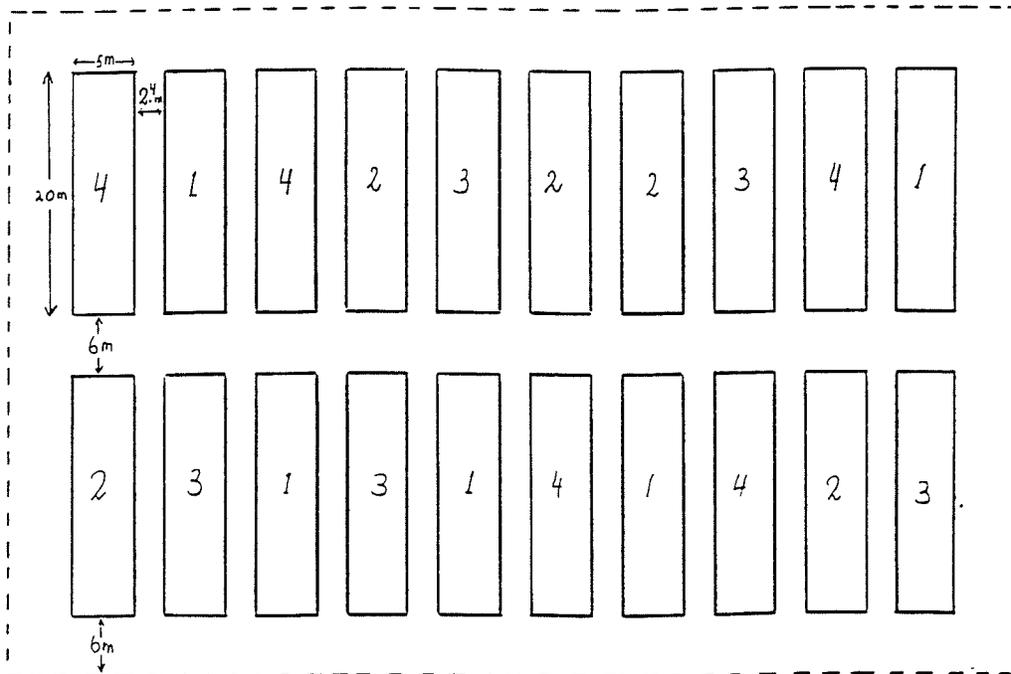


Fig. 3. Controlled environment chamber with rearing cages used to study the effect of temperature on nymphal development.



4 RESULTS

4.1 Species Composition

Three species of lygus bug adults were collected in oilseed rape during 1988 and 1989: L. lineolaris, L. borealis, and L. desertinus (TABLE 1). In addition, one specimen of L. vanduzeei Knight and one of L. unctuosus (Kelton) were encountered. The occurrence of the latter two species was considered incidental and they, therefore, were not included in the analysis.

Lygus lineolaris was the dominant species in all seedings in both 1988 and 1989 (TABLE 1 and Appendix 1). In 1989, L. desertinus was next in abundance, and L. borealis was, by far, the least abundant. The relative frequency of L. lineolaris was significantly greater in 1988 than in 1989 ($\chi^2 = 621.62$; d.f. = 1; $p < 0.01$). Lygus lineolaris made up 82.9% and 55.2%, of the pooled lygus bug adult samples in 1988 and 1989, respectively. Lygus borealis and L. desertinus together made up 17.1% of pooled samples of 1988. In 1989, L. borealis and L. desertinus made up 7.7% and 37.1%, respectively, of the pooled samples.

Lygus lineolaris, L. borealis, and L. desertinus were also present as nymphs on oilseed rape in 1988 and 1989. In 1988, 156 adult lygus bugs were reared from field-collected nymphs, of which 66.7% were L. lineolaris, 30.1% L. borealis, and 3.2% L. desertinus. In 1989, 338 adults were reared from field-collected nymphs, of which 60.1% were L. lineolaris, 13.3% L. borealis, and 26.6% L. desertinus. The relative frequency of L. lineolaris in the nymphal samples was not different from 1988 to 1989 ($\chi^2 = 2.24$; d.f. = 1; $p = 0.134$). However, the relative frequency of L. borealis nymphs was significantly lower ($\chi^2 = 19.91$; d.f. = 1; $p < 0.01$) and that of L. desertinus significantly

higher ($\chi^2 = 37.70$; d.f. = 1; $p < 0.01$) in 1989 than in 1988.

The species composition was significantly different among seedings in 1988 ($\chi^2 = 126.46$; d.f. = 3; $p < 0.01$) and in 1989 ($\chi^2 = 68.70$; d.f. = 6; $p < 0.01$) (TABLE 1). In 1988, the relative frequency of L. lineolaris was 70.2% in seeding 1 and gradually increased over subsequent seedings to 90.9% in seeding 4. In 1989, this pattern was not repeated for L. lineolaris. Not only was the range of relative frequency of L. lineolaris over the seedings smaller (from 52.6% in seeding 2 to 57.7% in seeding 4), the pattern of relative frequency also was different from 1988; the highest and the second highest relative frequencies occurred in seedings 4 and 1, respectively, and the lowest and second lowest in seedings 2 and 3, respectively. In 1989, the relative frequency of L. desertinus ranged from 30.4% in seeding 1 to 40.5% in seeding 3; the relative frequency was lowest in seeding 1, increased over seedings 2 and 3, and dropped slightly in seeding 4. Lygus borealis ranged from 5.5% in seeding 3 to 12.4% in seeding 1; the relative frequency was highest in seeding 1, decreased over seedings 2 and 3, and increased slightly in seeding 4.

The relative frequency of lygus bug species fluctuated relatively widely over the season in 1988 and 1989 (Figs. 4 and 5). The fluctuations in the relative frequency of L. lineolaris were larger in 1989 than in 1988 (Figs. 4 and 5). Lygus desertinus also fluctuated widely in 1989; it was the most abundant species on, at least, one sampling date in all seedings in 1989 (Fig. 5). Lygus borealis was the least abundant on most sampling dates in all seedings in 1989 (Fig. 5).

Relative species composition normally was independent among seedings on any sampling date (Figs. 4 and 5). Frequencies of lygus bug species were significantly different among seedings on five out of seven and six out of seven dates in 1988 and 1989, respectively. Species composition among seedings was compared on only those dates on

which all four seedings were sampled and each cell frequency was five or more.

The relative frequency of lygus bug species were similar between the pre-pod and pod stages of crop development in four of the seven seedings in 1988 and 1989 (TABLE 2). In 1988, the relative frequency of the three species was not significantly different between the pre-pod and pod stages in all three seedings. In 1989, only seeding 1 showed no significant differences in the species composition among the pre-pod and pod stages. In the second, third, and fourth seedings, the relative frequency of L. lineolaris was lower in the pod stage than in the pre-pod stage, and L. desertinus frequency was higher in the pod stage than in the pre-pod stage (TABLE 2).

TABLE 1. Numbers (N), relative frequencies (%), and counts (cnts/sample), of adults of three species of *Lygus* in samples from four seedings of oilseed rape (c.v. Westar) from the field experiments in 1988 and 1989 at Glenlea, Manitoba¹.

<i>Lygus</i> species	Seeding 1			Seeding 2			Seeding 3			Seeding 4		
	N	%	Cnts/samp. ² (S.E.)									
<u>1988</u>												
<i>L. borealis</i>	141	29.8	1.96(±0.39)a	147	24.1	2.16(±0.36)a	73	13.4	1.22(±0.14)a	93	9.1	2.11(±0.22)a
<i>L. desertinus</i>												
<i>L. lineolaris</i>												
	332	70.2	4.61(±0.96)b	463	75.9	6.81(±1.99)b	471	86.8	7.85(±1.01)b	931	90.9	21.16(±2.61)a
<u>1989</u>												
<i>L. borealis</i>	117	12.4	1.23(±0.19)b	173	8.8	2.04(±0.19)a	94	5.5	1.11(±0.15)b	94	6.2	1.34(±0.20)ab
<i>L. desertinus</i>	287	30.4	3.02(±0.18)b	755	38.6	8.88(±0.72)a	699	40.5	8.22(±0.65)a	544	36.1	7.77(±0.59)a
<i>L. lineolaris</i>	541	57.2	5.70(±0.44)b	1030	52.6	12.12(±1.52)a	931	54.0	10.95(±0.74)a	869	57.7	12.41(±1.36)a

¹ The numbers are totals for each species over the developmental period of oilseed rape.

² Mean counts per sample; means followed by the same letter within species are not significantly different (P > 0.05; Ryan-Einot-Gabriel-Welsch multiple range test).

³ The numbers are for *L. borealis* and *L. desertinus* combined.

Fig. 4. Relative frequency (%) of adults of L. lineolaris (____), L. desertinus and L. borealis combined (\\\\\\\\), in samples from four seedings of oilseed rape (c.v. Westar) from the 1988 field experiment at Glenlea, Manitoba.

'*', significant χ^2 ; 'n.s.', non-significant χ^2 ,

among seedings for sampling date:

28 Jul.: $\chi^2 = 23.43$, d.f. = 3, $p < 0.01$;

31 Jul.: $\chi^2 = 11.77$, d.f. = 3, $p < 0.01$;

04 Aug.: $\chi^2 = 30.62$, d.f. = 3, $p < 0.01$;

08 Aug.: $\chi^2 = 8.58$, d.f. = 3, $p < 0.01$;

11 Aug.: $\chi^2 = 11.92$, d.f. = 3, $p < 0.01$;

14 Aug.: $\chi^2 = 6.93$, d.f. = 3, $p = 0.07$;

19 Aug.: $\chi^2 = 5.72$, d.f. = 3, $p = 0.13$.

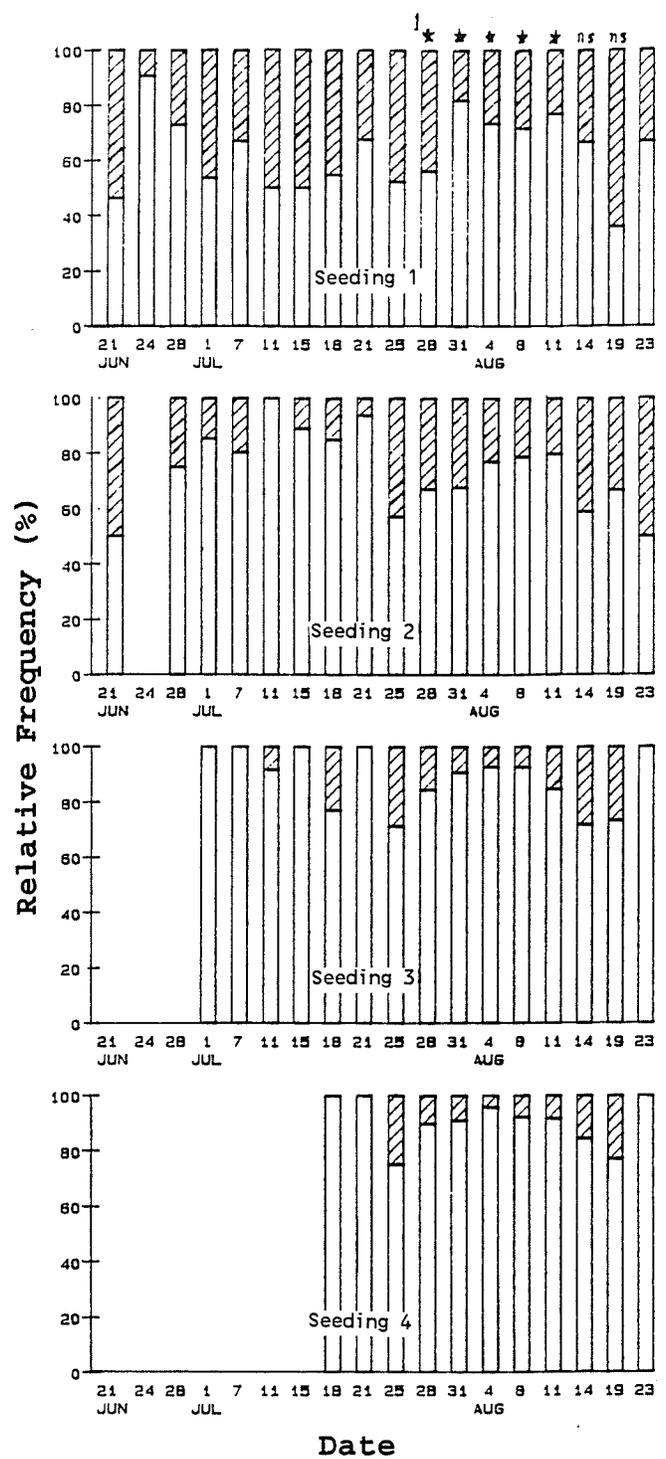


Fig. 5. Relative frequency (%) of adults of L. lineolaris (____), L. desertinus (/////), and L. borealis (\\\\\\\\), in samples from four seedings of oilseed rape (c.v. Westar) from the 1989 field experiment at Glenlea, Manitoba.

'*', significant χ^2 ; 'n.s.', non-significant χ^2 ,

among seedings for sampling date:

28 Jul.: $\chi^2 = 61.48$, d.f. = 6, $p < 0.01$;

01 Aug.: $\chi^2 = 31.33$, d.f. = 6, $p < 0.01$;

04 Aug.: $\chi^2 = 44.42$, d.f. = 6, $p < 0.01$;

08 Aug.: $\chi^2 = 41.29$, d.f. = 6, $p < 0.01$;

11 Aug.: $\chi^2 = 53.30$, d.f. = 6, $p < 0.01$;

14 Aug.: $\chi^2 = 71.08$, d.f. = 6, $p < 0.01$;

20 Aug.: $\chi^2 = 10.25$, d.f. = 6, $p = 0.11$.

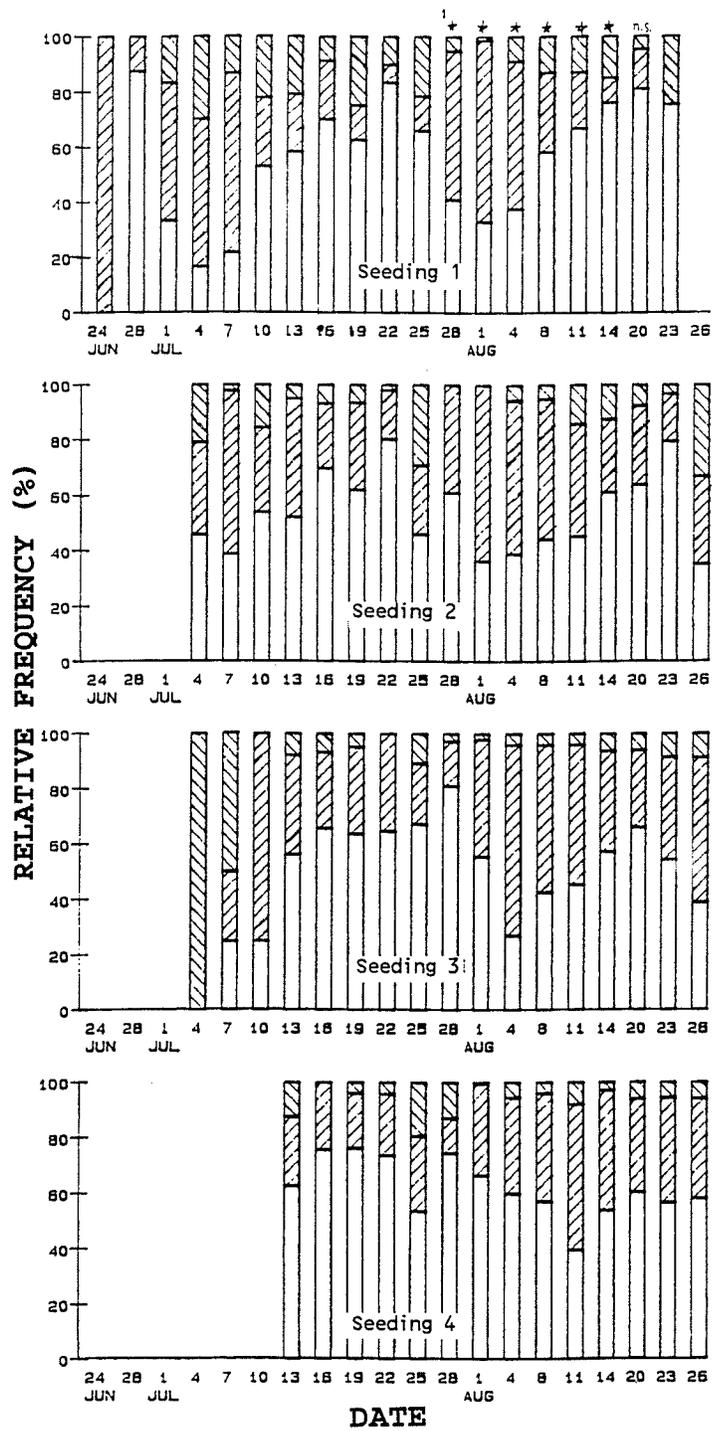


TABLE 2. Numbers (N) and relative frequencies (%) of adults of three species of *Lygus* at the pre-pod and pod development stages of oilseed rape (c.v. Westar), in samples from the field experiments in 1988 and 1989 at Glenlea, Manitoba.

Lygus species	Seeding 1				Seeding 2				Seeding 3				Seeding 4			
	Pre-pod ¹		Pod		Pre-pod		Pod		Pre-pod		Pod		Pre-pod		Pod	
	N	%	N	%	N	%	N	%	N	%	N	%	N	%	N	%
<u>1988</u>																
<i>L. borealis</i>	22	29.8	119	29.8	13	16.7	134	25.2	20	13.4	53	13.4	-	-	-	-
<i>L. desertinus</i>	52	70.2	280	70.2	65	83.3	398	74.8	129	86.6	342	86.6	-	-	-	-
<i>L. lineolaris</i>																
χ^2 -value*	0.00				2.701				0.00				-			
p-value*	0.987				0.100				0.999				-			
<u>1989</u>																
<i>L. borealis</i>	27	16.6	90	11.5	25	8.4	148	8.9	26	6.0	68	5.3	46	6.7	48	5.8
<i>L. desertinus</i>	52	31.9	235	30.1	95	32.0	660	39.7	121	27.9	578	44.8	212	31.0	332	40.4
<i>L. lineolaris</i>	84	51.5	457	58.4	177	59.6	853	51.4	286	66.1	645	50.0	427	62.3	442	53.7
χ^2 -value*	4.06				7.245				38.511				14.437			
p-value*	0.131				0.027				<0.01				<0.01			

¹ Pre-pod stage refers to the rosette, bud, and flowering stages combined.

² Pod development did not take place in seeding 4 in 1988.

³ The numbers are for *L. borealis* and *L. desertinus* combined.

* χ^2 -value and p-value pertain to the species distribution in the seeding above.

4.2 Development of Adult and Nymphal Lygus Bug Populations

Lygus bug adults were collected from the late rosette stages (stages 2.5 and 2.6) to the late pod stages (stages 5.4 to 5.5) of oilseed rape in 1988 and 1989 (Figs. 6 and 7). At first, only adults were collected, and then later on in the development of oilseed rape, both adults and nymphs were found (Figs. 6 and 7).

The first appearance of lygus bug adults occurred from the late rosette stages (stage 2.5 to 2.6) to the mid-bud stage (stage 3.2) (Figs. 6 and 7). In 1988, the adults first appeared at the end of the early bud stage (stage 3.1) in seedings 2 and 3 and at the late rosette stage (stage 2.6) in seeding 4 (Fig. 6). The first appearance of adults in seeding 1 was missed, because the plots could not be entered at the time due to irrigation. In 1989, the first appearance occurred at late rosette stages (stages 2.5 and 2.6) in seedings 1, 3, and 4, and at the mid-bud stage (stage 3.2) in seeding 2 (Fig. 7).

Among L. lineolaris, L. borealis, and L. desertinus, there were no consistent differences in the timing of first appearance of adults (Figs. 8 and 9). In 1988 and 1989, the first appearance of the three species occurred at about the same time in four out of the eight seedings. Lygus lineolaris occurred before the other two species in two seedings in 1988, and L. borealis and L. desertinus each occurred before the others in one seeding in 1989.

After the the initial appearance, lygus adult catch increased gradually in oilseed rape, reaching maxima during flowering (stages 4.1 to 4.4) (Figs. 6 and 7). In 1988, a maximum was reached at early flowering stages (stages 4.1 and 4.2) in seedings 1 and 2 and at the late flowering stage (stage 4.4) in seeding 3 (Fig. 6). The maximum

could not be determined in seeding 4, because the crop did not develop beyond the beginning of flowering due to the combined effects of drought and a heavy flea beetle (Phyllotreta spp.) infestation. In 1989, the maximum was reached at the early flowering stage (stage 4.2) in seedings 1 and 2 and at late flowering stages (stages 4.3 and 4.4) in seedings 3 and 4 (Fig. 7).

During flowering, the timing of maxima and median of L. borealis, L. desertinus, and L. lineolaris ranged from late bud to late flowering stages (stages 3.3 to 4.3) in 1988 and 1989 (Figs. 8 and 9). The exact timing of maximum catch of the three species was difficult to determine in most seedings of 1988 and 1989 due to either low catch levels or hard to define maxima (Figs. 8 and 9). The timing of the median showed no consistent differences among the three species (TABLE 5). In 1988, the median of L. lineolaris occurred at early flowering stages (stages 4.1 to 4.2) in seeding 1, from early to late flowering stages (stages 4.2 to 4.3) in seeding 2 and at late flowering stages (stages 4.3 to 4.4) in seeding 3. Seeding 4 did not develop beyond the beginning of flowering. The combined counts of L. borealis and L. desertinus reached its median at the same crop development stages as L. lineolaris. In 1989, L. lineolaris reached its median at early to late flowering stages (stages 4.2 to 4.3) in seedings 1 to 4. Lygus borealis reached the median at early to late flowering stages (stages 4.2 to 4.3) in seeding 1 and at the early flowering stages (stages 4.1 to 4.2) in seedings 2 to 4. Lygus desertinus reached its median at early flowering stages (stages 4.1 to 4.2) in seedings 1 to 3 and at early to late flowering stages (stages 4.2 to 4.3) in seeding 4. Lygus desertinus was earlier than L. lineolaris in the first three seedings of 1989 and the same in seeding 4.

After reaching a maximum during flowering, lygus bug adult catch decreased to a minimum in seedings 1 and 2 of 1988 and seedings 1, 2, and 3 of 1989 (Figs. 6 and 7). In 1988, the minimum was reached at

late flowering stages (stages 4.3 to 4.4) in seedings 1 and 2 (Fig. 6). Seeding 3 did not show a minimum during the late flowering stage. Seeding 4 did not develop beyond the beginning of the flowering stage. In 1989, a minimum also was reached at the late flowering stage (stage 4.4) in seedings 1 and 2. In seeding 3, evidence for a minimum at the late flowering (stage 4.4) was not conclusive, and in seeding 4, the catch increased gradually throughout flowering (Fig. 7).

The first lygus bug nymphs appeared in the plots after the first adults (Figs. 6 and 7). Nymphs were found for the first time 9, 14, and 10 days after the appearance of adults in seedings 2, 3, and 4, respectively, of 1988. The time elapsing until the first appearance of nymphs could not be determined in seeding 1, because data on first appearance of adults were missing (see above). In 1989, nymphs were first found 13, 12, 9, and 6 days after the appearance of the first adults in seedings 1, 2, 3, and 4, respectively.

The first lygus bug nymphs usually appeared at the flowering stage. In 1988, nymphs were found for the first time at early flowering stages (stages 4.1 to 4.2) in seedings 2, 3, and 4 and at the late flowering stage (stage 4.3) in seeding 1 (Fig. 6). In 1989, nymphs were found for the first time at the early flowering stage (stage 4.2) in seedings 1 and 2 (Fig. 7). In seedings 3 and 4, a small number of nymphs were found during the bud stage; nymphs started to be present in relatively large numbers at the early flowering stage (stage 4.1). During the flowering stages, the samples contained a mixture of nymphal instars, although the earlier nymphal instars were relatively more abundant in those samples taken from the earlier flowering stages than in those from the later crop stages (Figs. 6 and 7).

The times elapsed from the median of lygus bug adults during flowering and the median of the first nymphal instar, showed great differences between seeding 1 and seedings 2 and 3 of 1988. In 1989, the average times were close together in the first three seedings. In

seeding 4, this period was much shorter than in the previous seedings. In 1988, the average times were 24.5(\pm 2.9), 13.0(\pm 0.7), and 13.0(\pm 1.8) days in seedings 1, 2, and 3, respectively. In 1989, the average number of days were 9.2(\pm 1.0), 10.6(\pm 0.9), 10.4(\pm 2.1), and 5.0(\pm 0.4) in seedings 1, 2, 3, and 4, respectively.

The catch of lygus bug nymphs increased rapidly from the end of the flowering stage (stage 4.4) to the beginning of the pod stage (stage 5.2), reaching a maximum during pod development (Figs. 6 and 7). Within the seedings, the maxima for several nymphal instars often occurred simultaneously at the same stage of crop development (TABLE 3). Among seedings, the maxima for each nymphal instar were reached over a range of stages of crop development. In the 1988 and 1989, the first nymphal instar reached maximum catch from late flowering (stage 4.4) to early pod stages (stages 5.1 to 5.2), the second nymphal instar from late flowering (stage 4.4) to mid-pod development (stage 5.3), the third nymphal instar from late flowering (stage 4.4) to mid-pod development (stage 5.3), the fourth nymphal instar from early to mid-pod development (stages 5.1 to 5.3), and the fifth nymphal instar from early to late pod development (stages 5.2 to 5.4) (TABLE 3).

The times from planting date to the median of the nymphal instars showed much variation among the seedings (TABLE 3). The times from seeding of the median ranged from 52.9 to 78.1 days for the first nymphal instar, 54.2 to 79.3 days for the second nymphal instar, 55.2 to 80.4 days for the third nymphal instar, 56.5 to 80.5 days for the fourth nymphal instar, and 58.6 to 83.5 days for the fifth nymphal instar (TABLE 3).

The times between the median of the first and fifth nymphal instars also showed high variation among the seedings (TABLE 3). In 1988, the time between the median of the first and the fifth nymphal instar was 5.4 and 11.1 days in seedings 1 and 2, respectively, and in seeding 3 the median of the fifth nymphal instar was 0.7 days earlier

than that of the first nymphal instar. In 1989, the time between the first and fifth nymphal instar was 13.5, 13.7, 10.6, and 5.7 days in seedings 1, 2, 3, and 4, respectively.

After reaching maximum catch, the nymphal populations decreased rapidly in size. This decline was in order of succession of development of nymphal instars in 1989. In 1988, the decline in catch was in some instances inconsistent with succession of nymphal development; later instars reached low levels sooner than early instars (Figs. 6 and 7). The nymphal instars reached low numbers over a wide range of pod development stages (stages 5.2 to 5.5) among the seedings of 1988 and 1989 (Figs. 6 and 7). In 1988, most nymphal instars continued to be present in low numbers during late pod development stages (stages 5.4 to 5.5) in seedings 1, 2, and 3 (Fig. 6). Seeding 4 did not develop beyond flowering. In 1989, nymphs reached zero catch from stages 5.2 to 5.4 for the first nymphal instar in seedings 1 to 4; 5.3 to 5.5 for the second nymphal instar in seedings 1, 2, and 3; 5.4 to 5.5 for the third nymphal instar in seedings 1, 2, and 3; and 5.5 for the fourth and fifth nymphal instar in seeding 1 (Fig. 7). In the seedings not listed above, the catch of the respective nymphal instars did not reach zero during the experiment.

Shortly after the flowering stage, adult lygus bug catch increased again (Figs. 6 and 7). In 1988, numbers increased sharply at the beginning of the pod stage (stage 5.1) in seedings 1 and 2 and the end of the flowering stage (stage 4.4) in seeding 3 (Fig. 6). In 1989, sharp increases occurred at the beginning of the pod development stage (stages 5.1 and 5.2) in seedings 1 to 3 (Fig. 7).

Adult lygus bug catch reached a second maximum during pod development (stages 5.2 to 5.4) in seedings 1 and 2 of 1988 and seedings 1, 2, and 3 of 1989 (Figs. 6 and 7). These maxima were higher than those reached during flowering in 1988 and 1989 (TABLE 4). Maximum catch was reached at early pod development stage (stage 5.2) in

seeding 3 and at mid-pod development stage (stage 5.3) in seedings 1 and 2 in 1988. In 1989, the maximum catch occurred at early pod development stage (stage 5.2) in seeding 4, at mid-pod development stage (stage 5.3) in seeding 3, and at late pod development stage (stage 5.4) in seedings 1 and 2 (Figs. 6 and 7). Increases in adult catch were gradual during the pod stage. However, adult catch fell sharply after reaching the maximum catch in most seedings of 1988 and 1989.

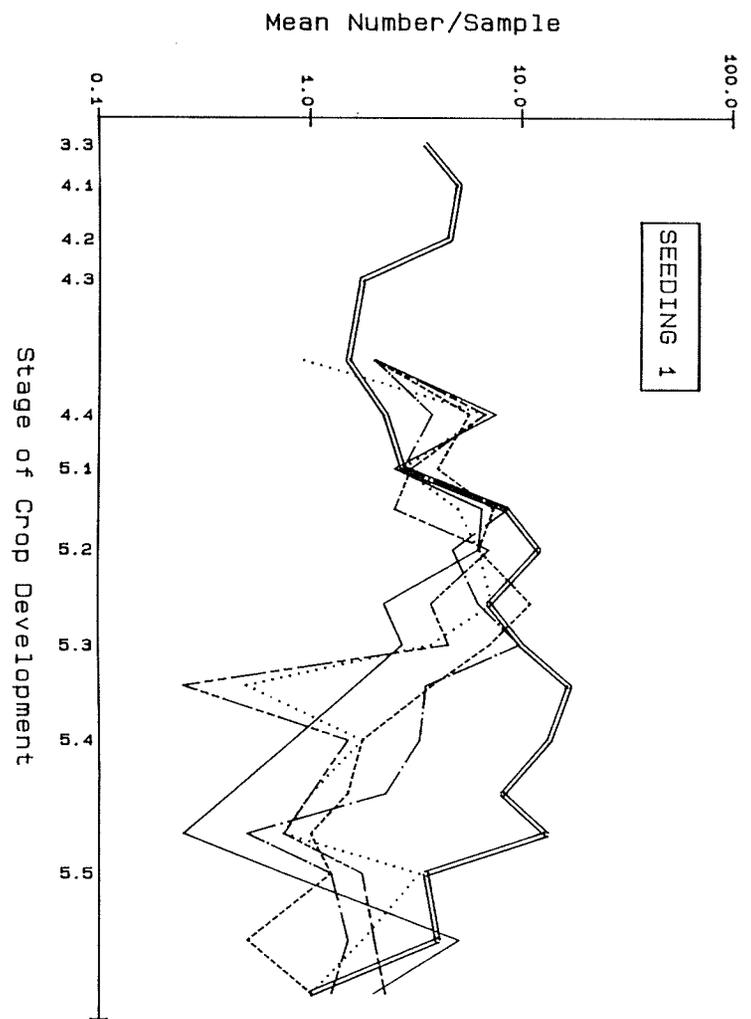
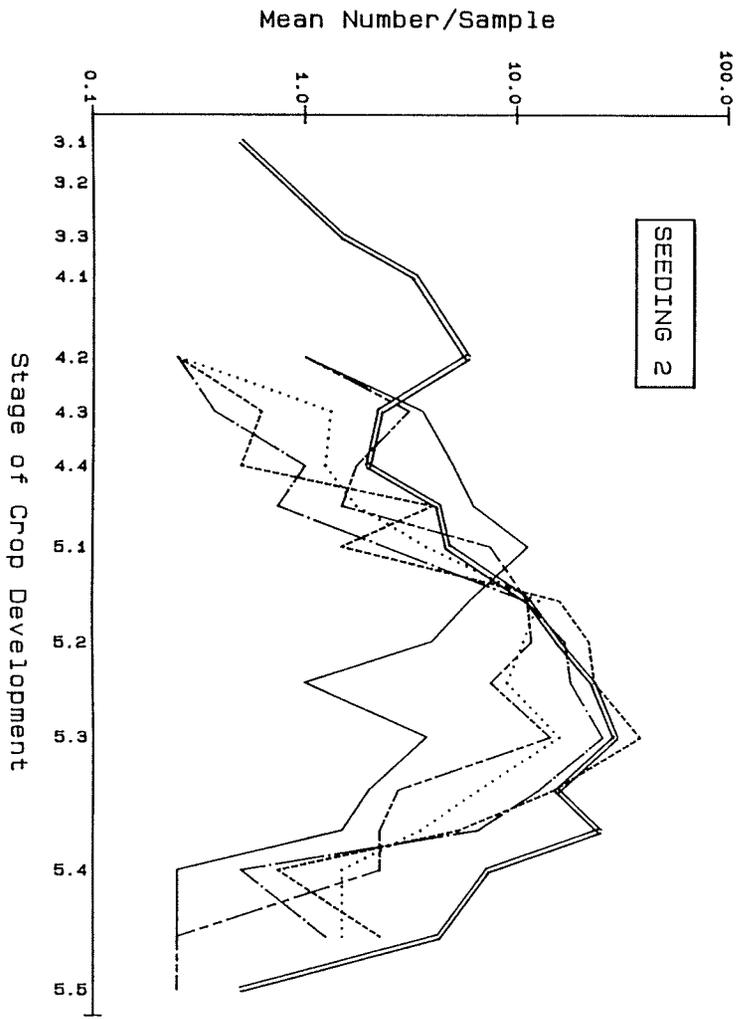
The average number of days from planting to the median of the adult population ranged from 56.0 to 87.3 among seedings in 1988 and 1989 (TABLE 3). The median of the adult population preceded the maximum in all seedings, except for seeding 1 of 1989. The median was 3.3 days later in seeding 1 of 1989 to 12.0 days earlier than the maximum in seeding 4 of 1989.

The maxima for the adults of L. lineolaris, L. desertinus, and L. borealis were reached at early to late pod development stages (stages 5.2 to 5.5) in 1988 and 1989 (Figs. 8 and 9). In 1988, L. lineolaris reached its maximum at stage 5.3 in seedings 1 and 2, and stage 5.2 in seeding 3 (Fig. 8). Counts of L. borealis and L. desertinus were combined in 1988, and therefore no specific data on maxima were available. In 1989, L. desertinus reached its maximum catch at an earlier stage of pod development than L. lineolaris (Fig. 9). Lyqus desertinus reached the maximum catch at stage 5.4, 5.3, and 5.2 in seedings 1, 2, and 3, respectively (Fig. 9, TABLE 5, and Appendix 2). Lyqus lineolaris reached its maximum catch at stage 5.5, 5.4, and 5.3, in seedings 1, 2, and 3, respectively. Lyqus borealis reached its maximum catch at the mid-pod development (stage 5.3) in seedings 2 and 3 and at the late pod development (stage 5.5) in seeding 1; these stages were similar to those for L. lineolaris. Lyqus desertinus reached its maximum 10, 3, and 3 days earlier than L. lineolaris in seedings 1, 2, and 3, respectively (TABLE 5). Lyqus

borealis reached its maximum at the same time as L. lineolaris in seedings 1 and 3 and at the same time as L. desertinus in seeding 2. In seeding 4, the catches of all three species levelled off during the pod development stages (stages 5.1 to 5.3), so that definite maxima could not be distinguished (Fig. 9).

The use of a sweep net as the sampling device to monitor lygus bug populations in the field experiments resulted in a distinctive pattern of distribution of counts among the nymphal instars. The size of the maximum catches in the samples increased with order of nymphal instars; maximum catches of early instars were less than those of later instars (Figs. 6 and 7). In 1988, the sizes of maximum catches of the nymphal instars were in order of succession of nymphal instars, but differences among the maxima were small (Fig. 6). In 1989, the sizes of maximum catches were in order of succession of nymphal instars in all seedings and the differences among the maxima were small only in seeding 4 (Fig. 7).

Fig. 6. Mean number of the first nymphal instar (—), second nymphal instar (___), third nymphal instar (·····), fourth nymphal instar (--), fifth nymphal instar (- · -), and adults (=====) of lygus bugs in the samples from the four seedings of oilseed rape (cv. Westar) from the 1988 field experiment at Glenlea, Manitoba.



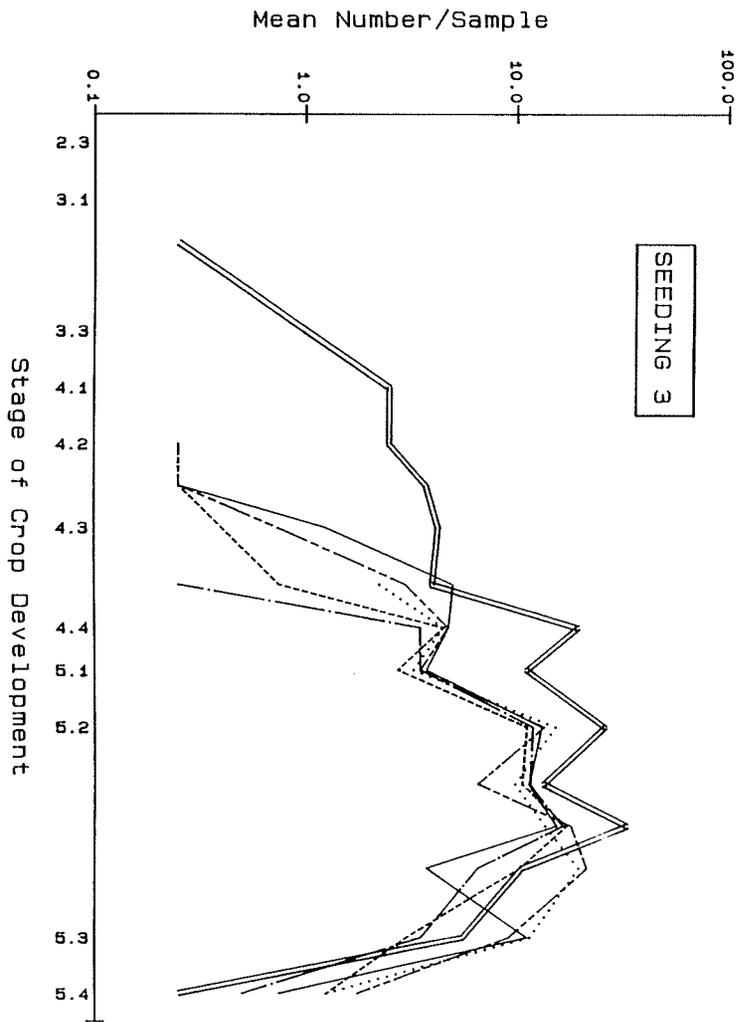
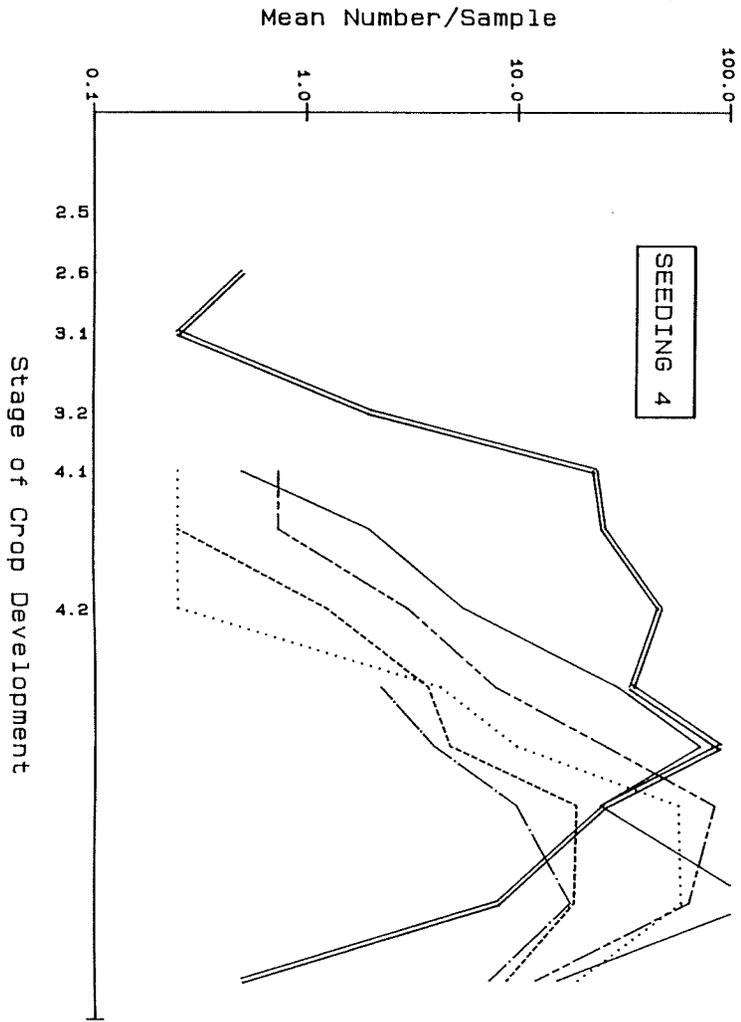
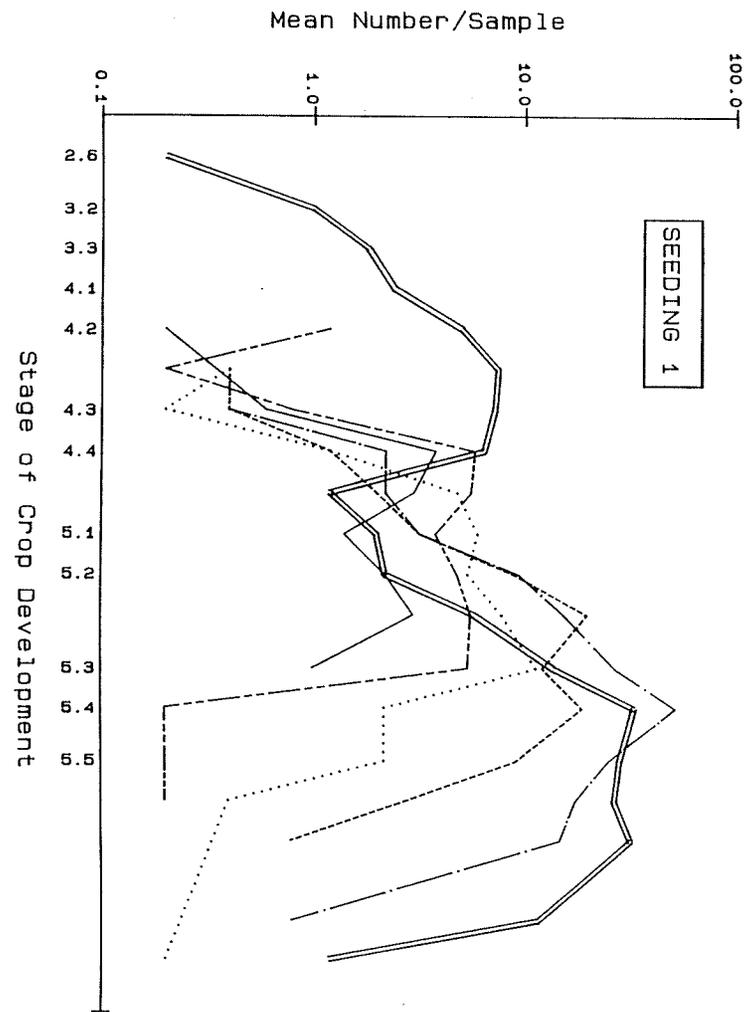
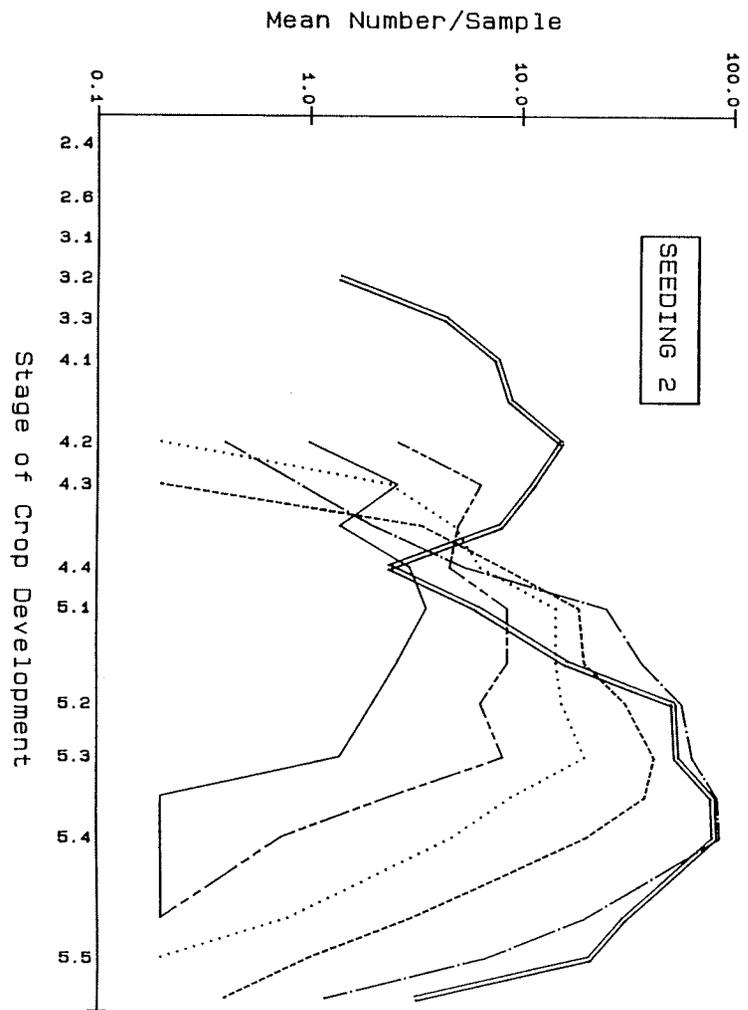


Fig. 7. Mean number of the first nymphal instar (—), second nymphal instar (___), third nymphal instar (·····), fourth nymphal instar (-----), fifth nymphal instar (- · -), and adults (=====) of lygus bugs in the samples from the four seedings of oilseed rape (cv. Westar) from the 1989 field experiment at Glenlea, Manitoba.



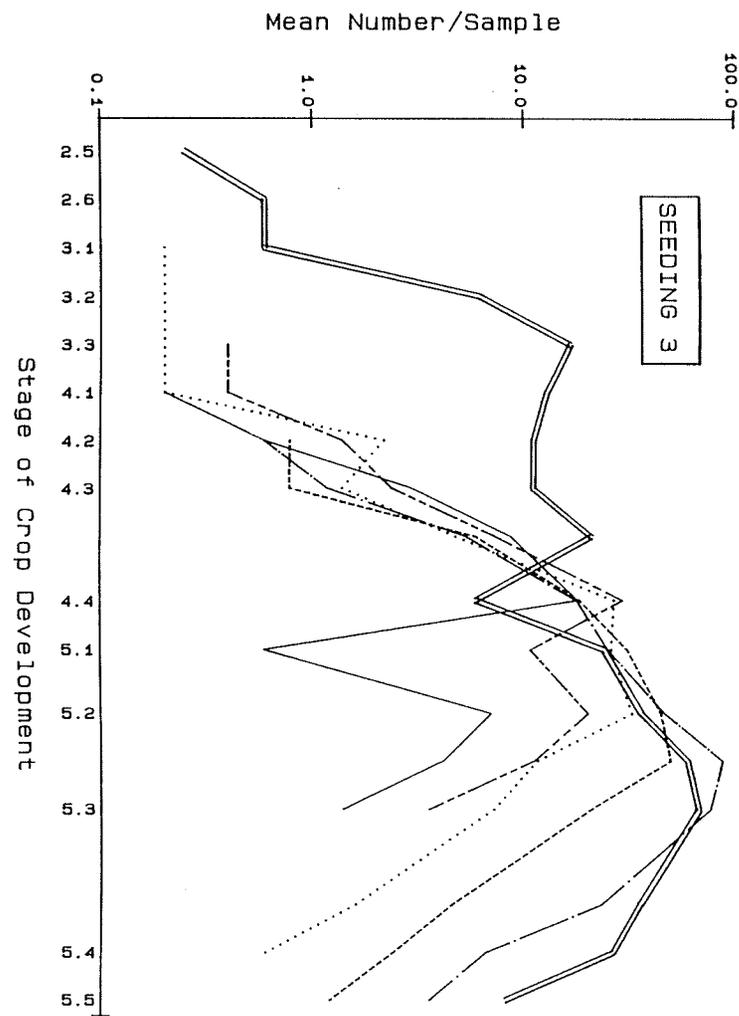
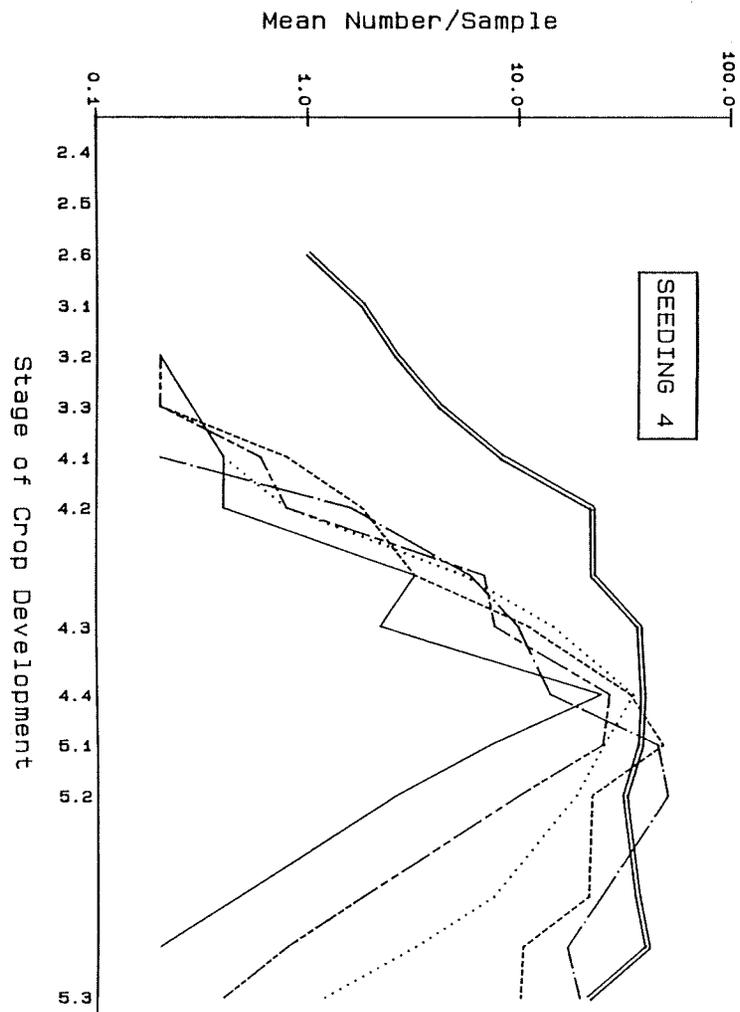
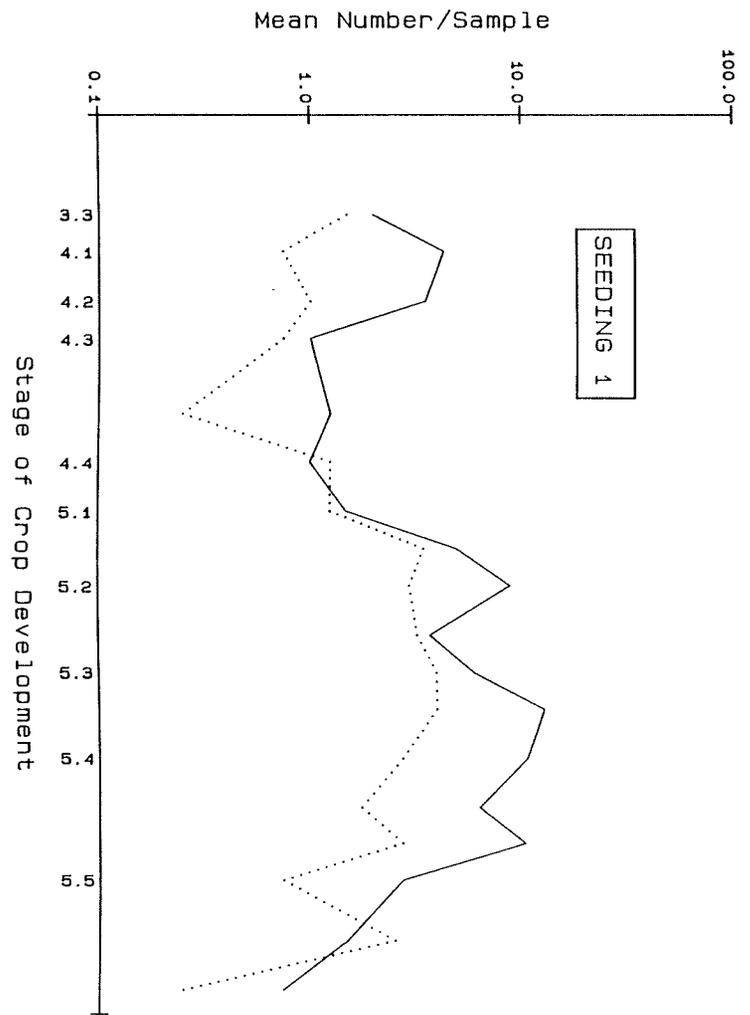
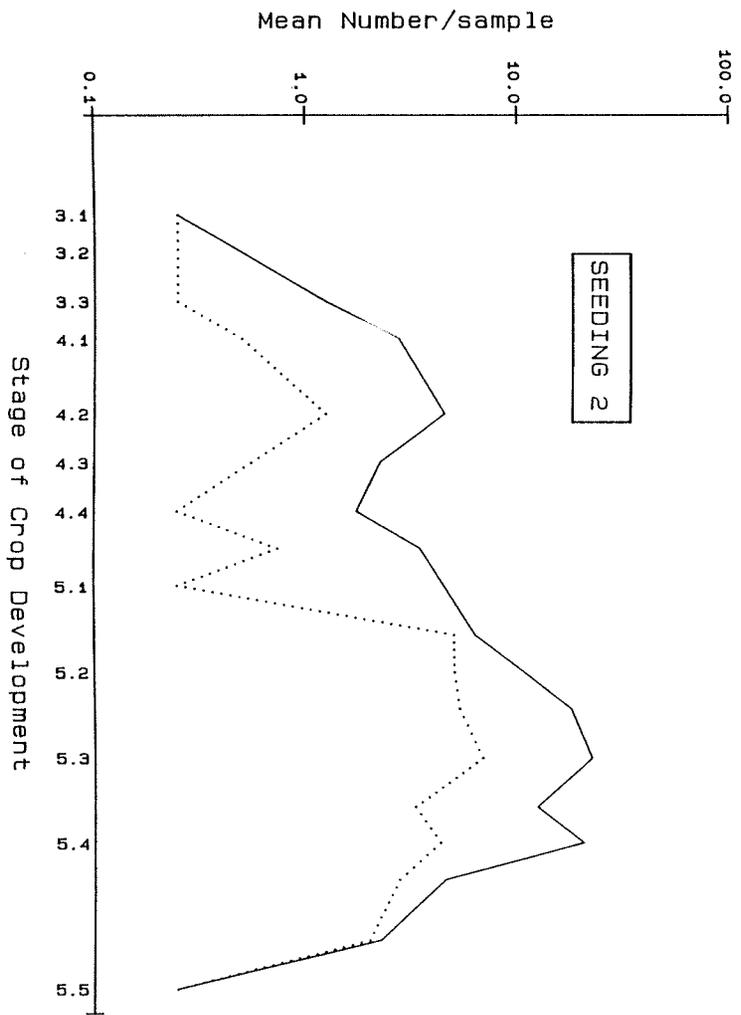


Fig. 8. Mean number of adults of L. lineolaris (—), and L. borealis and L. desertinus combined (·····) in samples from the four seedings of oilseed rape (cv. Westar) from the 1988 field experiment at Glenlea, Manitoba.



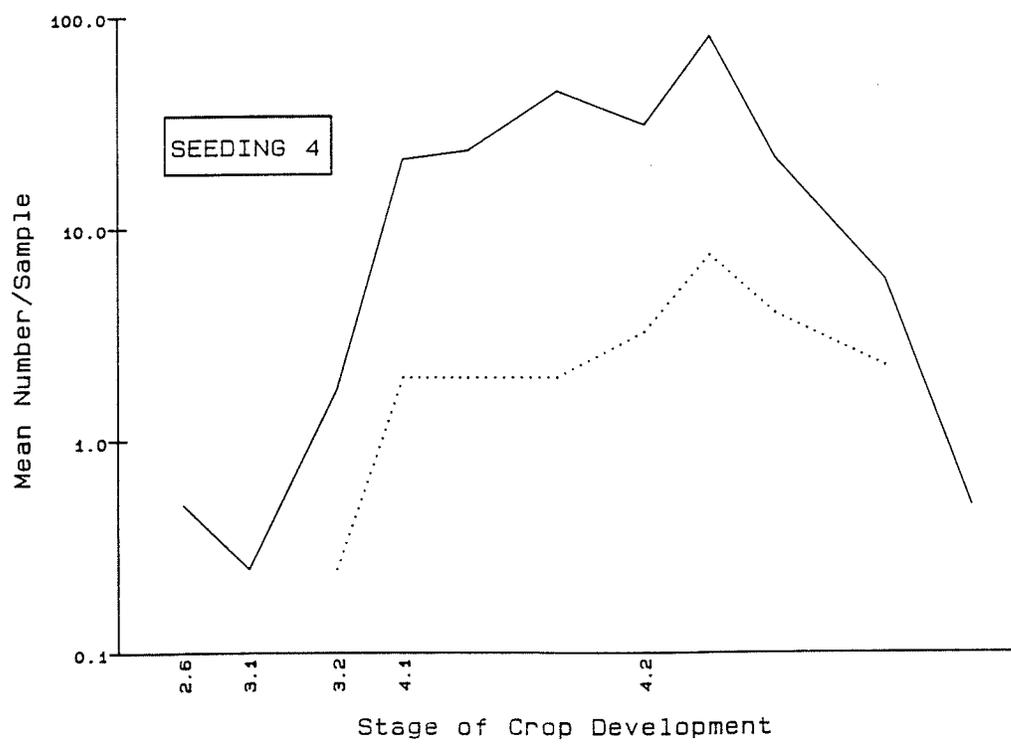
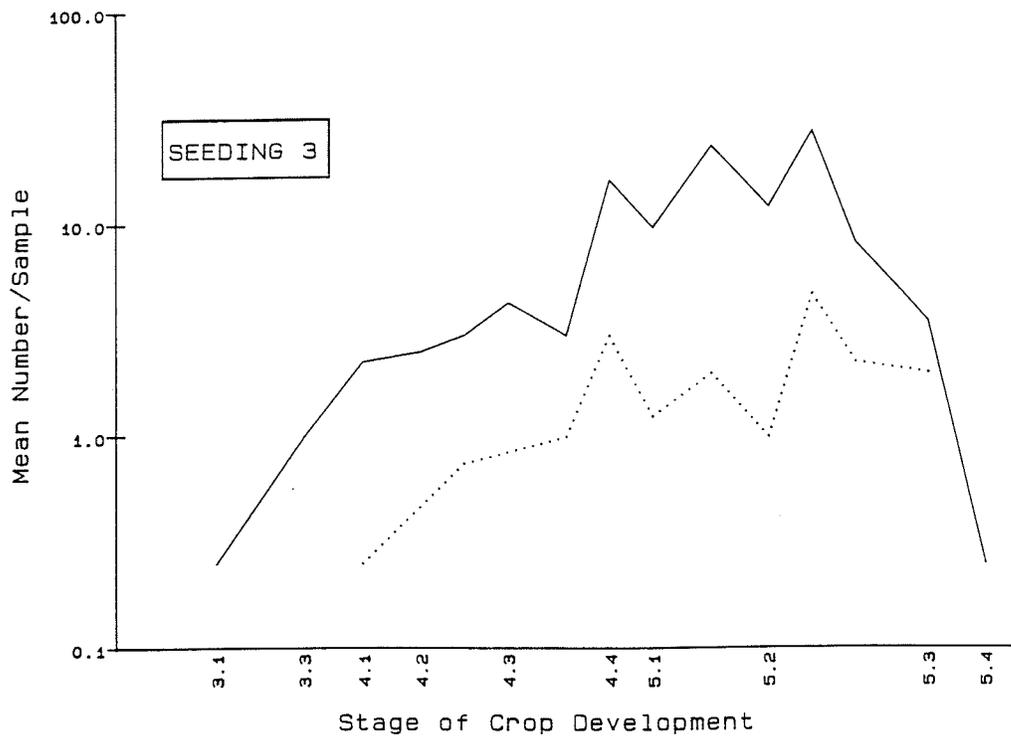
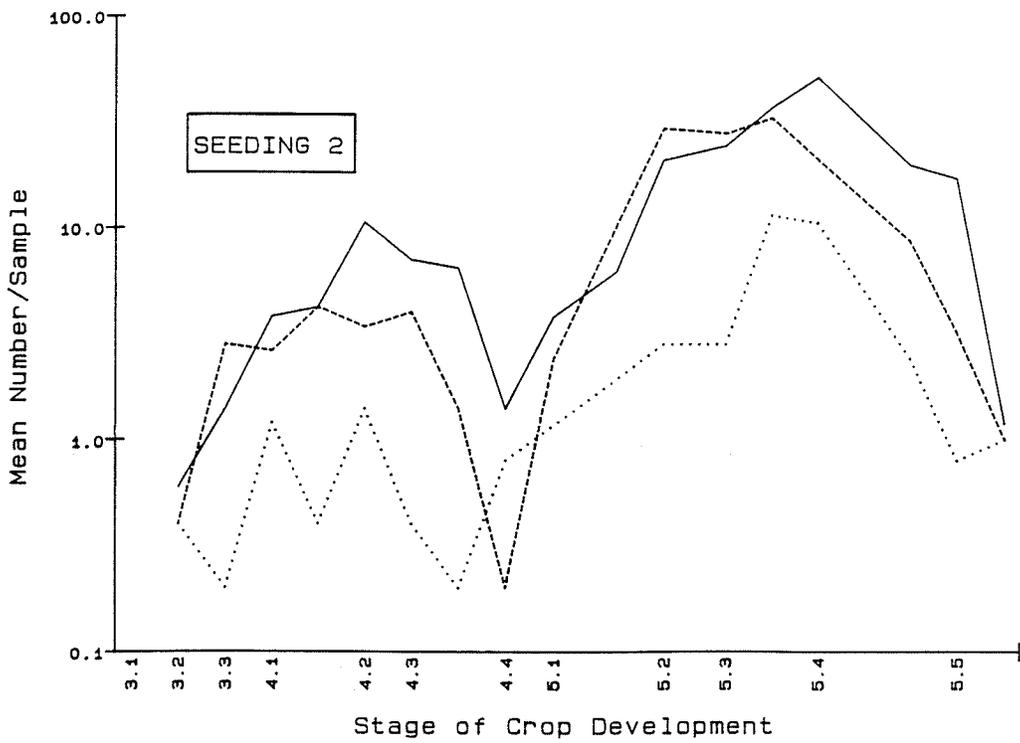
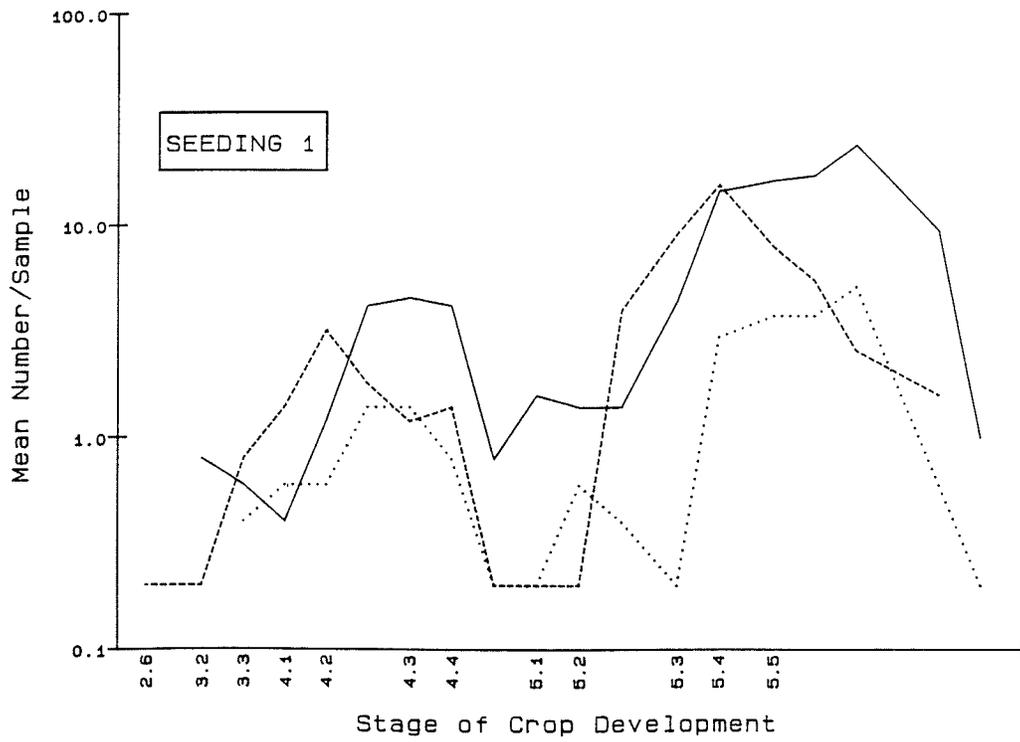


Fig. 9. Mean number of adults of L. lineolaris (—),
L. borealis (·····), and L. desertinus (-----) in
samples from the four seedings of oilseed rape (cv.
Westar) from the 1989 field experiment at Glenlea,
Manitoba.



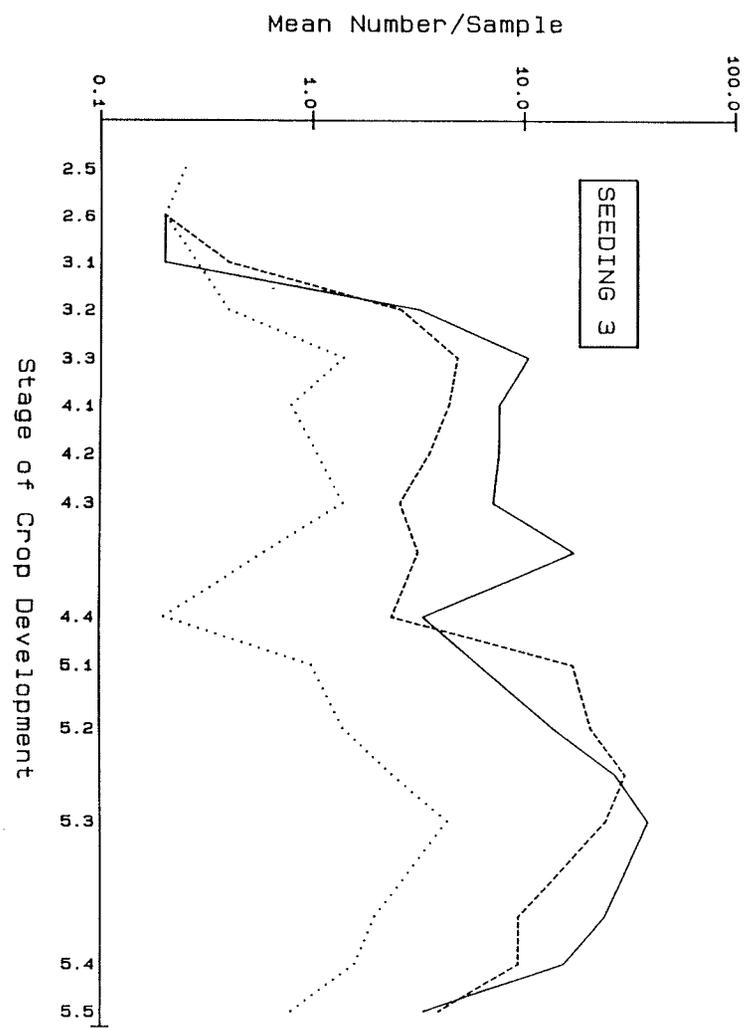
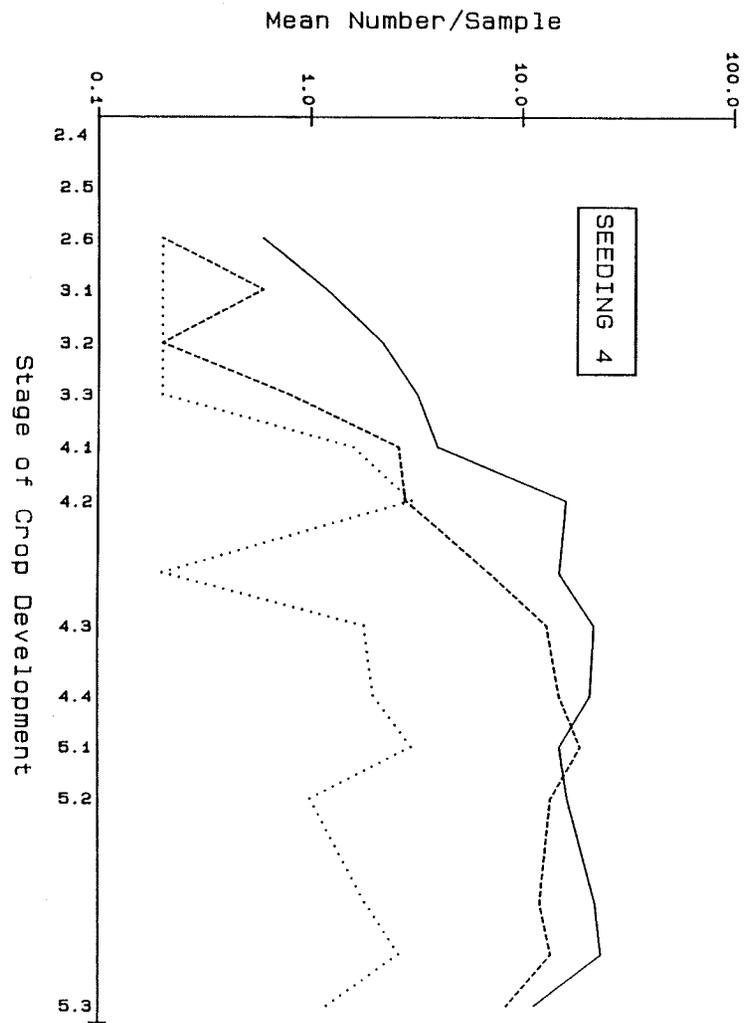


TABLE 3. Time after seeding (days) and stage of crop development when the maximum and median were reached for each stage of development of lygus bugs in samples from four seedings of oilseed rape (cv. Westar) from the 1988 and 1989 field experiments at Glenlea, Manitoba.

Seeding	Stadium	1988				1989			
		Maximum		Median		Maximum		Median	
		Time (days)	Crop Stage	Time(S.E.) (days)	Crop Stage	Time (days)	Crop Stage	Time(S.E.) (days)	Crop Stage
1 ¹	Nymph 1	69	4.4	78.1(±2.4)	5.1-5.2	60	4.4	65.6(±1.1)	4.4-5.1
1 ¹	Nymph 2	79	5.2	79.3(±0.8)	5.2	60	4.4	67.2(±1.2)	5.1-5.2
1 ¹	Nymph 3	83	5.2	80.4(±1.5)	5.2	76	5.3	71.2(±1.2)	5.2
1 ¹	Nymph 4	83	5.2	80.5(±1.1)	5.2	72	5.2	75.2(±0.5)	5.2-5.3
1 ¹	Nymph 5	86	5.3	83.5(±0.6)	5.2-5.3	79	5.4	79.1(±0.3)	5.4-5.5
1 ¹	Adults	89	5.3	87.3(±1.3)	5.3	79	5.4	82.3(±0.7)	5.4-5.5
2	Nymph 1	64	5.1	64.3(±0.4)	5.1	60	5.1	58.3(±0.9)	4.4-5.1
2	Nymph 2	78	5.3	71.5(±0.5)	5.2	64	5.1	61.2(±1.0)	5.1
2	Nymph 3	78	5.3	73.2(±0.8)	5.2	71	5.3	66.1(±0.4)	5.1-5.2
2	Nymph 4	78	5.3	74.9(±0.5)	5.2-5.3	71	5.3	70.0(±0.8)	5.2-5.3
2	Nymph 5	78	5.3	75.4(±0.3)	5.2-5.3	77	5.4	72.0(±0.9)	5.3
2	Adults	78	5.3	75.8(±0.8)	5.2-5.3	77	5.4	72.6(±0.5)	5.3
3	Nymph 1	71	5.2	68.2(±1.2)	5.2	56	4.4	56.6(±1.5)	4.4-5.1
3	Nymph 2	72	5.2	71.2(±0.7)	5.2	56	4.4	59.0(±1.0)	4.4-5.1
3	Nymph 3	79	5.3	70.8(±0.8)	5.2	63	5.2	60.6(±0.9)	5.1-5.2
3	Nymph 4	74	5.2	69.7(±0.7)	5.2	66	5.2	63.8(±0.6)	5.2
3	Nymph 5	71	5.2	68.9(±0.7)	5.2	66	5.2	67.2(±1.0)	5.2-5.3
3	Adults	71	5.2	65.3(±1.1)	5.1	69	5.3	65.9(±0.4)	5.2
4 ²	Nymph 1	--	--	--	--	53	4.4	52.9(±0.2)	4.3-4.4
4 ²	Nymph 2	--	--	--	--	53	4.4	54.2(±0.4)	4.4-5.1
4 ²	Nymph 3	--	--	--	--	53	4.4	55.2(±0.5)	4.4-5.1
4 ²	Nymph 4	--	--	--	--	53	5.1	56.5(±0.2)	5.1-5.2
4 ²	Nymph 5	--	--	--	--	59	5.2	58.6(±0.5)	5.1-5.2
4 ²	Adults	--	--	--	--	68	5.2	56.0(±1.1)	4.4-5.1

¹Times for seeding 1 of 1989 started on day of the first rains on 17 May 1989, eight days after planting.

²Seeding 4 of 1988 did not complete development beyond flowering.

TABLE 4. Mean numbers (\pm S.E.) per sample of adult lygus bugs during the first maximum catch at the flowering stage and the second maximum catch at the pod development stage in samples from the four seedings of oilseed rape (cv. Westar) from the 1988 and 1989 field experiments at Glenlea, Manitoba.

Seeding	1988		1989	
	Flowering	Pod development	Flowering	Pod development
1	5.0 (\pm 1.8)	16.8 (\pm 4.7)	7.4 (\pm 7.0)	33.2 (\pm 5.9)
2	5.8 (\pm 1.3)	29.0 (\pm 8.5)	15.4 (\pm 13.0)	82.5 (\pm 9.5)
3	19.3 (\pm 1.9)	32.5 (\pm 6.4)	21.2 (\pm 12.3)	67.6 (\pm 5.7)
4 ¹	--	--	38.0 (\pm 8.8)	39.8 (\pm 9.7)

¹ Seeding 4 of 1988 did not complete development beyond flowering.

TABLE 5. Time after seeding (days) and stage of crop development when the maximum catch and median were reached for adult *L. borealis*, *L. desertinus*, and *L. lineolaris* in samples from four seedings of oilseed rape (cv. Westar) from the 1989 field experiment at Glenlea, Manitoba.

Seeding	<i>L. borealis</i>				<i>L. desertinus</i>				<i>L. lineolaris</i>			
	Maximum		Median		Maximum		Median		Maximum		Median	
	Time (days)	Crop Stage	Time(S.E.) (days) ¹	Crop Stage	Time (days)	Crop Stage	Time(S.E.) (days) ¹	Crop Stage	Time (days)	Crop Stage	Time(S.E.) (days) ¹	Crop Stage
1 ²	90	5.5	85.5(±2.5)a	5.5	80	5.4	77.3(±1.4)b	5.3-5.4	90	5.5	83.8(±0.5)a	5.4 5.5
2	75	5.3	74.6(±0.5)a	5.3	75	5.3	70.9(±0.6)c	5.2-5.3	78	5.4	73.4(±0.7)b	5.3
3	70	5.3	65.9(±1.2)a	5.2	67	5.2	65.5(±0.4)a	5.2	70	5.3	66.1(±0.6)a	5.2
4	-- ³	-- ³	56.7(±2.7)a	4.4-5.1	-- ³	-- ³	56.9(±1.2)a	4.4-5.1	-- ³	-- ³	55.3(±1.3)a	4.4 5.1

¹Means followed by the same letter within each seeding are not significant ($P > 0.05$; Ryan-Einot-Gabriel-Welsch multiple range test).

²Times for seeding 1 of 1989 started on day of the first rains on 17 May, eight days after planting.

³Abundance of the species levelled off during the pod stage (stages 5.1 to 5.3) and therefore, maxima could not be determined.

4.3 Rate of Development in Relation to Temperature

4.3.1 Development of *L. lineolaris* in the Laboratory

The developmental times of nymphs of *L. lineolaris* decreased with each increase in constant temperature (TABLE 6). The times from emergence of the first nymphal instar to the emergence of the adults ranged from 19.6(\pm 1.3) days at 22.1°C to 41.8(\pm 1.9) days at 15.6°C (TABLE 6).

Mortality did not show any consistent patterns among the temperatures for all nymphal instars (TABLE 6). The distribution of average mortality among all temperatures was 8.1, 4.0, 3.0, 1.7, and 4.7% for nymphal instars 1 to 5, respectively (TABLE 6). There was no significant effect of temperature on overall mortality ($\chi^2 = 9.01$, d.f. = 4, $p = 0.061$).

The first and fifth nymphal instars occupied about one half of the developmental period from hatching to adult emergence (TABLE 6). The first and fifth nymphal instars occupied on average about 23 and 27%, respectively, of the developmental period. The remainder of the developmental period was divided almost equally among the second, third, and fourth nymphal instars. There were no significant effects of temperature on the proportion of time spent in each of the five nymphal instars.

The relationship between developmental rate (%/day) and temperature was linear at 15.6° to 22.1°C for all nymphal instars. The parameter estimates for the linear equations are given in TABLE 7. The estimated threshold temperatures of development ranged from 6.1 to 11.4°C among the nymphal instars (TABLE 7). The threshold temperature was estimated by solving the linear equation for rate of development equals zero. The threshold temperature was lowest for the first nymphal instar and increased for each subsequent instar, reaching

11.4°C for the fifth nymphal instar.

TABLE 6. Duration of development of the nymphal stages of *L. lineolaris* reared at five constant temperatures in the laboratory.

Temp- erat- ure °C	n	Nymphal Instar																				Overall mortal- ity, %	Mean time hatching to adult, days	SD	Range, days
		I				II				III				IV				V							
		Duration (days)				Duration (days)				Duration (days)				Duration (days)				Duration (days)							
mort. % ¹	Mean	SD	Range	mort. % ¹	Mean	SD	Range	mort. % ¹	Mean	SD	Range	mort. % ¹	Mean	SD	Range	mort. %	Mean	SD	Range						
22.1	117	9.4	5.1	0.9	3-9	13.2	3.4	0.8	2-6	3.3	3.0	0.6	2-5	4.6	3.3	0.6	2-5	3.5	4.8	0.7	3-7	29.9	19.6	1.3	17-25
19.9	93	7.5	5.4	0.7	4-7	0	3.5	0.6	2-5	0.8	3.6	0.6	3-5	0.8	4.1	0.6	3-6	0.8	6.2	0.7	5-8	10.8	22.8	1.5	20-26
19.3	73	8.2	5.4	0.9	4-5	0.7	4.0	0.7	3-6	4.7	3.7	0.7	2-5	0.6	4.3	0.8	2-7	1.2	6.4	0.6	5-8	17.8	23.7	1.9	21-28
18.5	110	10.0	5.6	1.0	3-8	6.1	4.3	0.7	2-6	5.4	4.2	0.7	3-7	2.3	4.6	0.6	3-6	4.7	7.2	0.7	6-9	25.5	25.5	1.5	22-29
15.6	94	5.3	8.8	1.1	6-12	0	6.5	0.8	4-8	0.8	6.4	0.8	2-8	0	7.9	0.9	3-10	13.4	12.3	1.1	11-18	18.1	41.8	1.9	38-46

¹ Apparent mortality (Southwood 1978).

TABLE 7. Estimates of parameter values for the linear equation relating developmental rate (%/day) to constant temperature (°C) and of degree days (DD) to complete develop for the nymphal instars of L. lineolaris.

Nymphal Instar	Intercept (\pm SE)	Slope (\pm SE)	n	r ²	P (slope)	Threshold (C°)	DD
First	-7.98 (\pm 5.06)	1.32 (\pm 0.29)	5	0.870	0.01	6.1	75.7
Second	-18.74 (\pm 7.57)	2.25 (\pm 0.39)	5	0.916	<0.01	8.3	44.4
Third	-27.06 (\pm 2.86)	2.76 (\pm 0.15)	5	0.991	<0.01	9.8	36.2
Fourth	-28.97 (\pm 2.72)	2.70 (\pm 0.14)	5	0.992	<0.01	10.7	37.0
Fifth	-22.23 (\pm 1.21)	1.94 (\pm 0.06)	5	0.997	<0.01	11.4	51.7

4.3.2 Rate of Development in the Field

The developmental data in the field in 1988 and 1989 are given in Figures 10 and 11 and TABLE 8. In 1988, the mean duration of the developmental period from the median of the first nymphal instar to the median of the adult stage was 12.9 and 14.7 days in seedings 1 and 2, respectively. In seeding 3, the results appeared anomalous; the median of the adult stage preceded that of the first nymphal instar. Data for seeding 4 were not available, because the crop did not develop beyond the flowering stage. In 1989, the duration was 19.9, 16.7, 12.2, 11.5 days in seedings 1, 2, 3, and 4, respectively.

The observed times of the medians for the nymphal instars and the adults in the field were compared with the expected times. The median of the first instar nymph was the starting point for estimating predicted development from the first nymphal instar to the adult stage. Degree days were summed over the developmental period of the nymphal instars to determine the expected times of the medians for the nymphs and the adults (TABLE 8).

The observed times of the median of the adult stage was earlier than the expected times in all seedings in 1988 and in seedings 2 to 4 in 1989. In seeding 1 in 1989, the observed timing was later than the expected (Figs. 10, 11, and TABLE 8). Differences between observed and expected, in paired t-tests, were significant in seeding 3 in 1988 ($t = 7.14$; d.f. = 3; $p < 0.01$), and in seedings 2, 3, and 4 in 1989 ($t = 3.221$, d.f. = 4, $p = 0.0323$; $t = 5.341$, d.f. = 4, $p < 0.01$; $t = 13.847$, d.f. = 4, $p < 0.01$, respectively).

The difference between the observed and expected times for the median of the adult stage usually increased with date of seeding. In

1988, the difference between the expected and observed was largest in the third seeding. In 1989, the differences increased consistently with seeding date.

Fig. 10. Mean date (day of the year \pm S.E.) of the observed (-----) and expected (——) times of the median of the nymphal instars (I to V) and the adults (Ad.) of L. lineolaris from the samples from the first three seedings of oilseed rape (cv. Westar) from the 1988 field experiment at Glenlea, Manitoba.

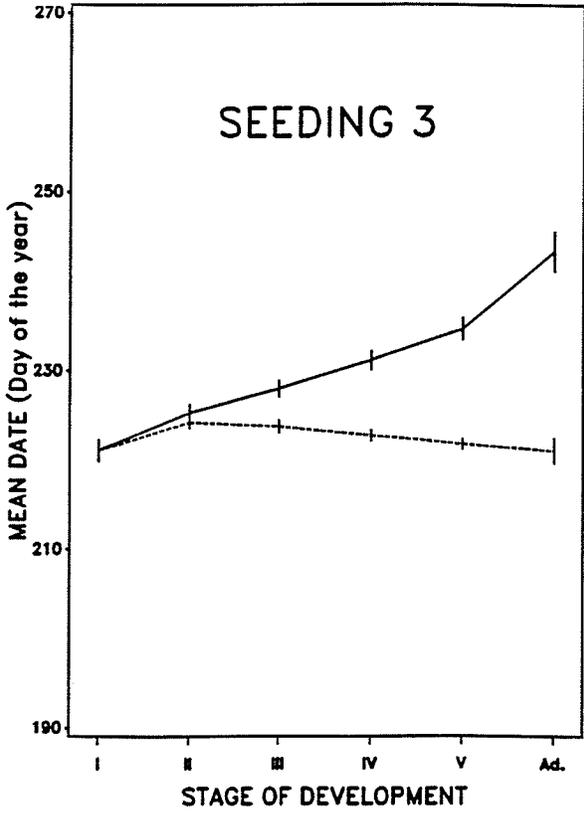
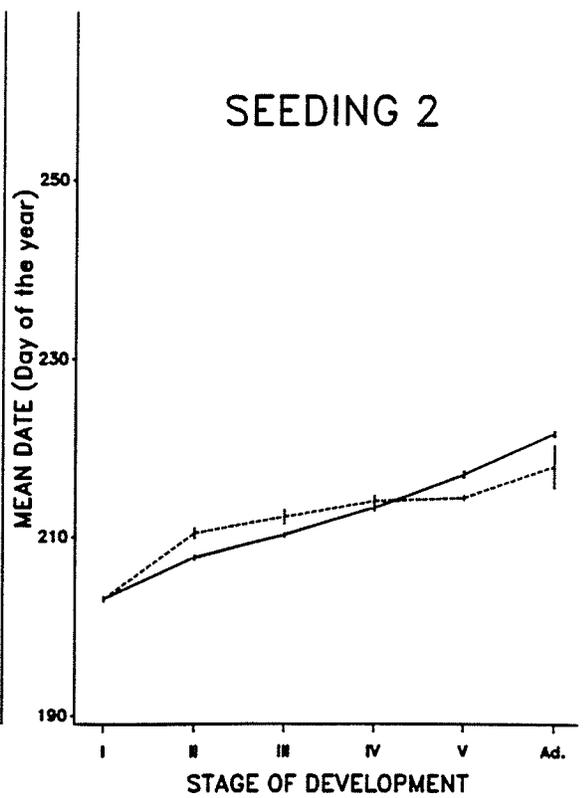
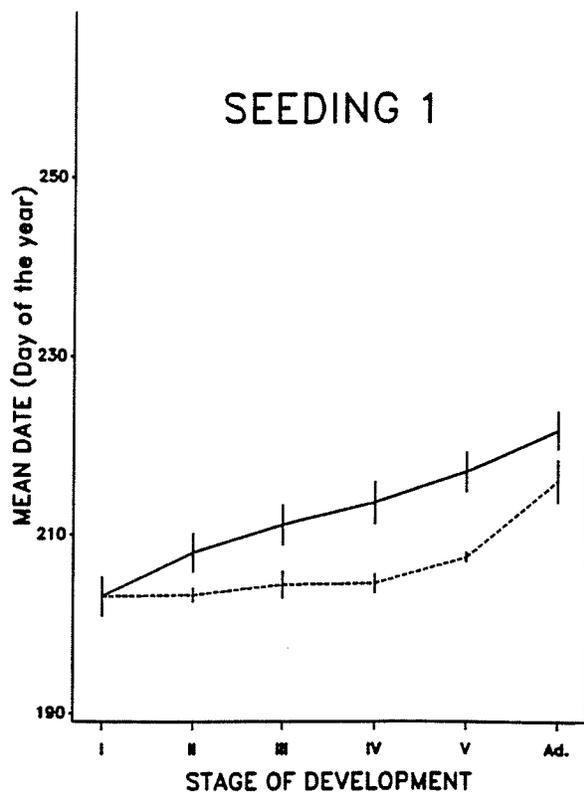


Fig. 11. Mean date (day of the year \pm S.E.) of the observed (-----) and expected (——) times of the median of the nymphal instars (I to V) and the adults (Ad.) of L. lineolaris from the samples from the four seedings of oilseed rape (cv. Westar) from the 1989 field experiment at Glenlea, Manitoba.

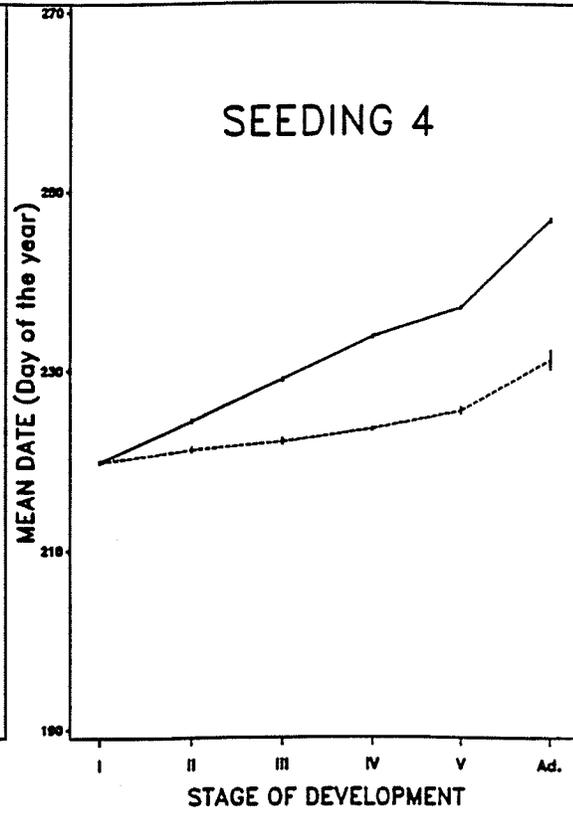
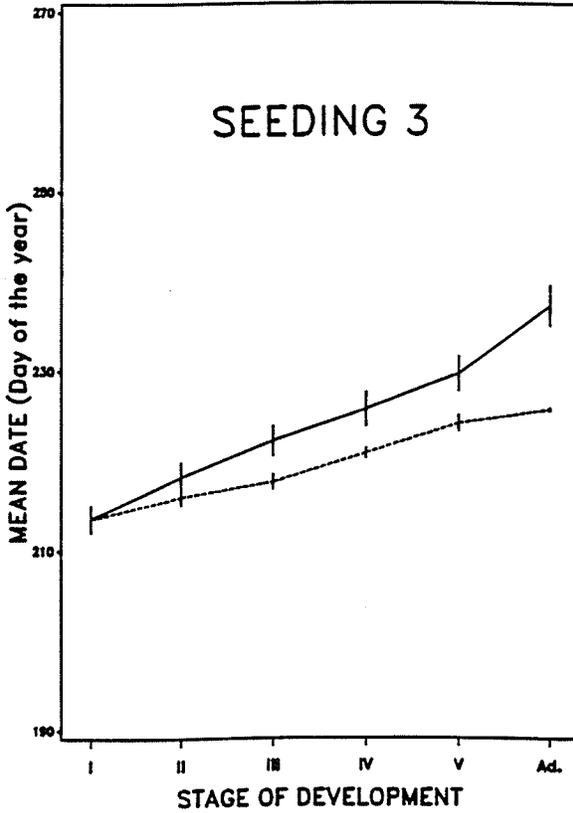
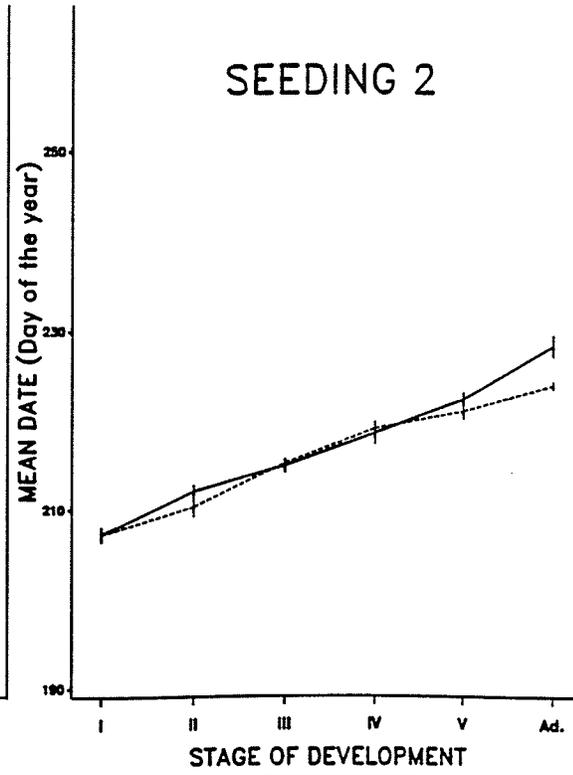
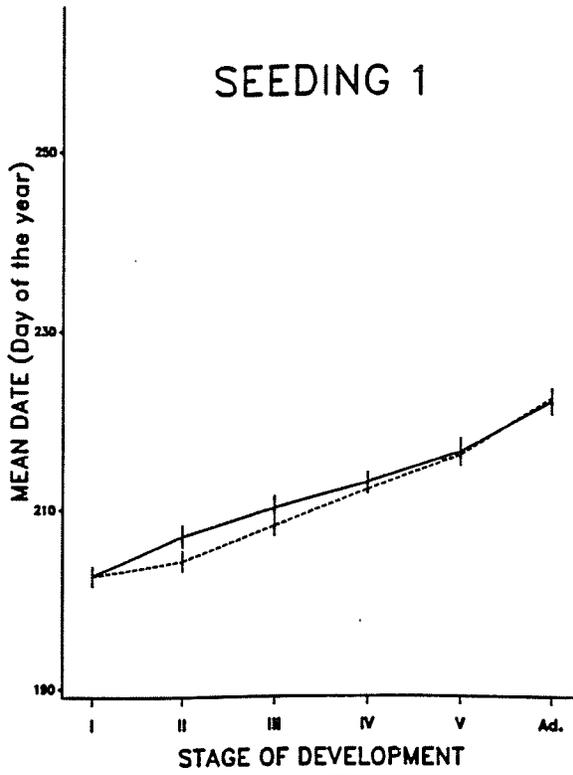


TABLE 8. Observed and expected mean times (day of the year) of the median and the difference between these two times for the nymphal instars (I to V) and the adults of *L. lineolaris* on the three or four seedlings of oilseed rape (cv. Westar) from the 1988 and 1989 field experiments at Glenlea, Manitoba.

Instar	Seedlings											
	1			2			3			4		
	Obs.	Exp.	Dif.	Obs.	Exp.	Dif.	Obs.	Exp.	Dif.	Obs.	Exp.	Dif.
<u>1988</u>												
I	203.1	203.1	-	203.1	203.1	-	221.1	221.1	-			
II	203.3	208.0	-4.7	210.5	207.8	+2.7	224.2	225.2	-1.0			
III	204.4	211.1	-6.7	212.2	210.2	+2.0	223.8	228.0	-4.2			
IV	204.5	213.5	-9.0	214.0	213.3	+0.7	222.7	231.1	-8.4			
V	207.5	217.3	-9.8	214.4	217.0	-2.6	221.8	234.7	-12.9			
Adult	216.0	221.8	-5.8	218.0	221.7	-3.7	221.1	243.4	-22.3			
<u>1989</u>												
I	202.6	202.6	-	207.3	207.3	-	213.6	213.6	-	219.9	219.9	-
II	204.3	207.0	-2.7	210.3	212.0	-1.7	216.0	218.2	-2.2	221.2	224.4	-3.2
III	208.2	210.1	-1.9	215.1	214.8	+0.3	217.6	222.2	-4.6	222.1	229.0	-6.9
IV	212.2	213.6	-0.8	219.0	218.4	+0.6	220.8	225.7	-4.9	223.5	233.7	-10.2
V	216.1	217.0	-0.3	221.0	222.3	-1.3	224.2	229.7	-5.5	225.6	237.0	-11.4
Adult	222.5	222.1	+0.4	224.0	228.4	-4.4	225.8	237.3	-11.5	231.3	246.9	-15.6

5 DISCUSSION

5.1 Species Composition

The simultaneous occurrence of more than one lygus bug species on a crop is common (Butts 1989; Craig 1983; Domek and Scott 1985; Fye 1982b). Species assemblages of lygus bugs on oilseed rape have been found in Alberta (Butts 1989). However, the species assemblage in oilseed rape at Glenlea, Manitoba, was different from that found in Alberta. Lygus desertinus was common in Manitoba, but is absent in Alberta; and L. elisus was absent in Manitoba, but is common in Alberta. The dominant species in Manitoba was L. lineolaris. In Alberta, L. elisus was the dominant species in four of the five years (Butts 1989).

The species composition of lygus bugs varied from year to year. Though L. lineolaris was the dominant species, it was relatively less abundant in 1989 than in 1988. Variations in relative species composition have been noted in oilseed rape in Alberta; L. lineolaris replaced L. elisus as the dominant species in one out of five years (Butts 1989).

The wildly fluctuating relative abundances of lygus bug species throughout the development of oilseed rape are likely due to the small sample sizes of adults and constant changing of the relative species composition due to lygus bugs moving into and out of the oilseed rape. Lygus bugs are flighty insects, and move among host plants (Boivin and Stewart 1983b; Fleischer et al. 1988; Mueller and Stern 1973).

The species composition of the adults reared from field-collected nymphs confirms that L. borealis, L. desertinus, and L. lineolaris reproduce on oilseed rape. The similarities in the relative abundances of lygus adults on the pre-pod and the pod stages in four out of seven

seedings indicates that the early samples provided a good measure of the capabilities of the three species to reproduce on oilseed rape. Studies in Alberta on oilseed rape (Butts 1989) and on weeds in Washington (Fye 1982b) also showed that when adults are found on a plant they usually oviposit and their offspring develop on it as well.

5.2 Development of Adult and Nymphal Lygus Bug Populations

The lygus bug adults first appeared on the reproductive stages of oilseed rape. This timing was consistent regardless of seeding date, indicating that the stage of plant development was an important factor in attracting lygus bugs to oilseed rape. Similarly, in Alberta, the start of the reproductive stages of oilseed rape was identified as the main factor influencing the time of invasion of lygus bugs (Butts 1989). Other crops also are invaded during the reproductive stage of development. Cotton is attacked during the development of the early flower buds (Tugwell et al. 1976). Birdsfoot trefoil (Lotus corniculata L.) is invaded when newly formed floret buds are available. Apple and peach trees are attacked during the bud and flowering stages (Hauschild and Parker 1976; Phillips and DeRonde 1966). On uncultivated host plants, lygus bugs appeared when the plants entered the bud or flowering stage (Boivin et al. 1981; Fleischer and Gaylor 1987).

The first lygus bug nymphs appeared one to two weeks after the first appearance of the adults. According to Ridgway and Gyrisco (1960a), the incubation of eggs of L. lineolaris lasts 15 days at 20°C and 8 days at 25°C. Daily average temperatures at Glenlea from the time of first appearance of adults in seeding 1 to the first appearance of nymphs in seeding 4 were 19.9°C and 20.4°C in 1988 and 1989,

respectively (Agriculture Canada Monthly Climatological Message for Canadian Weather Review, Glenlea Station, 1988 and 1989). The time between the appearance of the first adults and nymphs indicated that lygus bugs already had partially or completely developed eggs at the time of invasion and started to lay eggs soon after invasion.

In Manitoba, lygus bugs completed one generation on oilseed rape. A single generation is indicated by the occurrence of two peaks of adults separated by successive peaks of the five nymphal instars. These results were the same as for lygus bugs on oilseed rape in Alberta (Butts 1989).

The maxima and median abundances of the nymphal instars and the second peak of adults occurred during the pod development stages of oilseed rape. This timing of occurrence of nymphs in all seedings indicated that their development occurred during the development of pods and seeds of oilseed rape and was independent of time of seeding. Maxima often occurred at the same time for more than one nymphal instar, which likely is a result of poor resolution of timing due to low sampling frequency. In Alberta, maximum numbers of lygus bug nymphs and second adults also appeared on the pod development stages of oilseed rape (Butts 1989). Development of lygus bug nymphs on the reproductive structures also has been reported for beans (Khattat and Stewart 1975), cotton (Tugwell et al. 1976), and weeds (Boivin et al. 1981; Khattat and Stewart 1980).

The adults of the second peak disappeared from oilseed rape soon after emergence. This was indicated by the steep decline of adult abundance soon after reaching the peak in most seedings. A fast decline in abundance has been attributed to lygus bugs moving away from the original host plant because of the deterioration of the host during the ripening process (Anderson and Schuster 1983, Hagel 1978, Stern et al. 1964).

The median and peak abundances for the second peak of adult L. desertinus usually were earlier than those for L. borealis and L. lineolaris. These results indicated differences in timing of development of these lygus species on oilseed rape. This is the first study to show differences in the rate of development of lygus species on any host plant.

The counts of the later nymphal instars were higher than those of the earlier nymphal instars. This pattern was similar to that in a study of lygus bugs on oilseed rape by Butts (1989). In this study, sweep net sampling also was used. Sweep net estimates are influenced by a number of factors such as habitat, species, vertical distribution of the insects in the crop, and diel cycles of movement (Southwood 1978). Boivin and Stewart (1983a) used a beating technique to sample L. lineolaris nymphs on apples, and found that the efficiency of sampling increased with later instars. Apparently, later instars are dislodged more easily than younger ones, and this likely is the explanation why sweep nets are catching fewer specimens of earlier nymphal instars than later nymphal instars of lygus bugs on oilseed rape.

5.3 Rate of Development in Relation to Temperature

5.3.1 Development of L. lineolaris in the Laboratory

Temperature had a significant effect on the rate of development in L. lineolaris. The developmental times were similar to those from other studies on L. lineolaris. Bariola (1969) found that the developmental times from egg hatching to the adult stage are on average 34.2 days at 16.0°C and 19.9 days at 21°C. Fleischer and Gaylor (1988), studying development on several host species, found

developmental times ranging from 25.5 to 33.2 days at 18°C and from 16.2 to 22.6 days at 22°C. The latter observation is close to the observed developmental time in this study at 22.1°C. It took the first and the fifth nymphal instar the longest and the third nymphal instar the shortest time to develop at a given temperature. Fleischer and Gaylor (1988) also found this to be the case.

The estimated threshold temperatures for development increased with each nymphal instar. Fleischer and Gaylor (1988) also found that the estimated threshold for L. lineolaris was lowest in the first nymphal instar. However, the threshold temperatures for the other nymphal instars did not show the same trend; the third nymphal instar had the highest threshold (Fleischer and Gaylor 1988). Bariola (1969) found that no nymphs would develop beyond the second instar when reared at 11°C. Neither the present study nor that of Fleischer and Gaylor (1988) investigated the growth rates at temperatures below 15°C. The estimated threshold temperatures in the present study were 0.7 to 3.6°C lower for the first four and 0.6°C higher for the fifth instar than those in the study of Fleischer and Gaylor (1988).

5.3.2. Development of L. lineolaris under Field Conditions

The rate of development from the median of the first nymphal instar to the adult stage of in the field was earlier than expected in most seedlings of 1988 and 1989. Other studies which investigated the effects of temperature on insects under field and laboratory conditions have reported similar results (Lamb and Gerber 1985; Purcell and Welter 1990).

Exposure to direct sunlight may raise the body temperature of insects up to 15°C over the air temperature (Heinrich 1981). Lamb and Gerber (1985) suggested that exposure to direct sunlight accounted for

faster development of the red turnip beetle (Entomoscelis americana Brown) in the field. Because lygus bugs feed on young reproductive and meristematic plant tissues (Tingey and Pillemer 1977), which usually are located in the more terminal parts of plants, it is likely they are exposed to direct sunlight with the result that body temperatures are higher than air temperatures.

The drought conditions during most of the 1988 and part of the 1989 growing season also may have contributed to higher body temperatures in the lygus bugs. Moisture stress and drought conditions can affect the temperature close to the plant surface. Commonly, temperatures are 2 to 4°C higher on the leaf surfaces of water stressed plants than on well-watered plants (Mattson and Haack 1987). This is a result of reduced transpirational cooling in moisture stressed plants (Begg 1980). Leaves of Brassica oleracea are 2 to 3°C warmer under drought stressed conditions than under normal conditions (Clum 1926).

5.4 Application in Pest Management

A survey of oilseed rape fields in Manitoba showed an average seed loss of 13% in four out of the five geographical districts of southern Manitoba (Turnock et al. 1989). These losses of rape seed are substantial (Butts 1989; Turnock et al. 1989), and therefore, control of lygus bugs in oilseed rape in Manitoba is being considered. Timing of control measures is an important consideration for efficient management of pest insects in crops (Luckmann and Metcalf 1982). This study showed that the lygus bug adults invaded oilseed rape during the flowering stage. From 1 to 2 weeks later, the first nymphs appeared and nymphal populations grew very rapidly during the early pod development stages. Chemical control of the early nymphal instars during the early pod development stages of crop development should keep

nymphal populations low during most of the remainder of pod development.

Prediction of occurrence of lygus bug populations on the basis of temperature did not give reliable results. The stage of development of oilseed rape is at present the only reliable variable with which to predict the occurrence and development of nymphal and adult populations. Prediction of the times of median and peak abundances of lygus bug nymphal and adult populations is of value in developing future pest management programs for lygus bugs in oilseed rape.

6 CONCLUSIONS

The principal findings of the present studies are:

1. Three species of lygus bugs occurred on oilseed rape in Manitoba:
L. borealis, L. desertinus, and L. lineolaris.
2. Lygus bugs had one generation on oilseed rape.
3. Lygus bug adults first appeared at the beginning of the
flowering stage of oilseed rape.
4. The first nymphs appeared one to two weeks after the first
appearance of the adults.
5. The peak and median abundances of the nymphal instars occurred
during the early to late pod development stages of oilseed
rape.
6. The second peak of the adults occurred during the pod development
stages of oilseed rape.
7. All three species of lygus bugs reproduced on oilseed rape.
8. The second peak of adults of L. desertinus was earlier than those
of adults of L. borealis and L. lineolaris.

9. Development of L. lineolaris was dependent on temperature in the laboratory. The relationship between developmental rate (%/day) and temperature was linear at 15.6° to 22.1°C.

10. The estimated threshold temperature for nymphal development was 6.1, 8.3, 9.8, 10.7, and 11.4°C, for the first to the fifth nymphal instars, respectively.

11. Ambient air temperature was a poor indicator for lygus bug development on oilseed rape under field conditions. The observed times of the median of the nymphal instars and the adult stage usually were earlier than the expected times.

Knowledge of the timing of development of lygus bugs on oilseed rape can be used to design future pest management schemes. The following information could be used for such schemes. Lygus bug adults first appear in the crop at the beginning of the flowering stage. Nymphs appear one to two weeks later. The peak abundances of the nymphal instars and of the new adults occur during the pod development stages. Peak appearances of lygus bugs, therefore, are predictable by using the stage of crop development as the indicator for lygus bug development.

REFERENCES

- Al-Munshi, D.M. , D.R. Scott, and H.W. Smith. 1982. Some plant host effects on Lygus hesperus (Hemiptera: Miridae). J. econ. Ent. 75: 813-815.
- Alvarado-Rodriguez, B., T.F. Leigh, K.W. Foster, and S.S. Duffey. 1986. Resistance in common bean (Phaseolus vulgaris) to Lygus hesperus (Heteroptera: Miridae). J. econ. Ent. 79: 484-489.
- Alvarado-Rodriguez, B., T.F. Leigh, K.W. Foster, and S.S. Duffey. 1987. Life tables for Lygus hesperus (Heteroptera: Miridae) on susceptible and resistant common bean cultivars. Environ. Ent. 16: 45-49.
- Anderson, R.A., and M.F. Schuster. 1983. Phenology of the tarnished plant bug on natural host plants in relation to populations in cotton. The SW. Ent. 8: 131-134.
- Ave, D., J.L. Frazier, and L.D. Hatfield. 1978. Contact chemoreception in the tarnished plant bug, Lygus lineolaris (Heteroptera: Miridae). Entomologia exp. appl. 24: 217-227.
- Bailey, J.C., A.L. Scales, and W.R. Meredith, Jr.. 1984. Tarnished plant bug (Heteroptera: Miridae) nymph numbers decreased on caged nectariless cotton. J. econ. Ent. 77: 68-69.

- Bariola, L.A.. 1969. The biology of the tarnished plant bug, Lygus lineolaris (Beauvois), and its nature of damage and control on cotton. Ph.D. Thesis. Texas AM Univ., College Station. 102pp..
- Baskerville, G.L., and P. Emin. 1969. Rapid estimation of heat accumulation from maximum and minimum temperatures. Ecology 50: 514-517.
- Begg, J.E.. 1980. Morphological adaptations of leaves to water stress. pp. 33-42. In: N.C. Turner and P.J. Kramer (eds.): Adaptation of Plants to Water and High Temperature Stress. Wiley, New York.
- Benedict, J.H., T.F. Leigh, and A.H. Hyer. 1983. Lygus hesperus (Heteroptera: Miridae) oviposition behavior, growth, and survival in relation to cotton trichome density. Environ. Ent. 12: 331-335.
- Benedict, J.H., T.F. Leigh, A.H. Hyer, and P.F. Wynholds. 1981. Nectariless cotton: effect on growth, survival, and fecundity of lygus bugs. Crop Sci. 71: 28-30.
- Boivin, G., G. Mailloux, R.O. Paradis, and J.G. Pilon. 1981. La punaise terne, Lygus lineolaris (P. de B.) (Hemiptera: Miridae), dans le sud-ouest du Québec. II. Fluctuations saisonnières des populations sur certaines mauvaises herbes. Ann. ent. Soc. Queb. 26: 159-169.
- Boivin, G., and R.K. Stewart. 1983a. Sampling technique and seasonal development of phytophagous mirids (Hemiptera: Miridae) on apple in southwestern Quebec. Ann. ent. Soc. Am. 76: 359-364.

- Boivin, G., and R.K. Stewart. 1983b. Seasonal development and interplant movements of phytophagous mirids (Heteroptera: Miridae) on alternate host plants in and around an apple orchard. *Ann. ent. Soc. Am.* 76: 776-780.
- Bosque-Perez, N.A., T.F. Leigh, and K.W. Foster. 1982. Oviposition, survival, growth, and observed population increase of Lygus hesperus (Heteroptera: Miridae) on selected bean cultivars. *J. econ. Ent.* 75: 997-1001.
- Bracken, G.K.. 1987. Relation between pod damage caused by larvae of bertha armyworm, Mamestra configurata Walker (Lepidoptera: Noctuidae), and yield loss, shelling, and seed quality in canola. *Can. Ent.* 119: 365-369.
- Butler, G.D., Jr.. 1968. Sugar for the survival of Lygus hesperus on alfalfa. *J. econ. Ent.* 61: 854-855.
- Butler, G.D., Jr.. 1972. Flight times of Lygus hesperus. *J. econ. Ent.* 65: 1299-1300.
- Butts, R.A. 1989. Biology and damage assessments of Lygus spp. infesting oilseed brassicas grown in Alberta. Ph.D. Thesis, Univ. of Manitoba, Winnipeg. 158pp.
- Campbell, A., B.D. Frazer, N. Gilbert, A.P. Gutierrez, and M. Mackauer. 1974. Temperature requirements of some aphids and their parasites. *J. appl. Ecol.* 11: 431-438.

- Cave, R.D., and A.P. Gutierrez. 1983. Lygus hesperus field life table studies in cotton and alfalfa (Heteroptera: Miridae). Can. Ent. 115: 649-654.
- Cleveland, T.C.. 1982. Hibernation and host plant sequence studies of tarnished plant bugs, Lygus lineolaris, in the Mississippi delta. Environ. Ent. 11: 1049-1052.
- Clum, H.H.. 1926. The effect of transpiration and environmental factors on leaf temperatures I. Transpiration. Am. J. Bot. 13: 194-216.
- Cohen, A.C.. 1982. Water and temperature of two hemipteran members of a predator-prey complex. Environ. Ent. 11: 715-719.
- Cota, J.A., 1980. Feeding behavior of Lygus hesperus Knight: methods for measuring plant resistance. Dissertation abstracts International, B (Sciences and Engineering). 2050 B order no. 8027045. Univ. of California, Davis.
- Craig, C.H. 1983. Seasonal occurrence of Lygus spp. (Heteroptera:Miridae) on alfalfa in Saskatchewan. Can. Ent. 115: 329-331.
- Crosby, C.R., and M.D. Leonard. 1914. The tarnished plant bug, Lygus pratensis L.. Cornell Agr. Exp. Sta. Bull. 346: 463-525.

- Curtis, C.E., and C.E. McCoy. 1964. Some host preferences shown by Lygus lineolaris (Hemiptera: Miridae) in the laboratory. Ann. ent. Soc. Am. 57: 511-513.
- Domek, J.M., and D.R. Scott. 1985. Species of the genus Lygus Hahn and their host plants in the Lewiston-Moscow area of Idaho (Hemiptera:Miridae). Entomography 3: 75-105.
- Elmore, J.C.. 1955. The nature of lygus bug injury to lima beans. J. econ. Ent. 48: 148-151.
- Environment Canada. 1983. Canadian Climatic Normals, 1951-1980. Temperature and Precipitation. Prairie provinces. pp.1-429.
- Fleischer, S.J., and M.J. Gaylor. 1987. Seasonal abundance of Lygus lineolaris (Heteroptera:Miridae) and selected predators in early season uncultivated hosts: implications for managing movement into cotton. Environ. Ent. 16: 379-389.
- Fleischer, S.J., and M.J. Gaylor. 1988. Lygus lineolaris (Heteroptera: Miridae) population dynamics: nymphal development, life tables, and leslie matrices on selected weeds and cotton. Environ. Ent. 17: 246-25
- Fleischer, S.J., M.J. Gaylor, and N.V. Hue. 1988. Dispersal of Lygus lineolaris (Heteroptera: Miridae) adults through cotton following nursery host destruction. Environ. Ent. 17: 533-541.

- Flemion, F, L.P. Miller, and R.M. Weed. 1952. An estimate of the quantity of oral secretion deposited by Lygus when feeding on bean tissue. Contrib. Boyce Thompson Inst. Pl. Res. 16: 429-433.
- Fye, R.E.. 1982a. Overwintering of lygus bugs in central Washington: effects of pre-overwintering host plants, moisture, and temperature. Environ. Ent. 11: 204-206.
- Fye, R.E.. 1982b. Weed hosts of the lygus (Heteroptera: Miridae) bug complex in central Washington. J. econ. Ent. 75: 724-727.
- Graham, H.M., and C.G. Jackson. 1982. Distribution of eggs and parasites of Lygus spp. (Hemiptera: Miridae), Nabis spp. (Hemiptera: Nabidae), and Spissistilus festinus (Say) (Homoptera: Membracidae) on plant stems. Ann. ent. Soc. Am. 75: 56-60.
- Graham, H.M., A.A. Negm, and L.R. Ertle. 1984. Worldwide literature of the Lygus complex (Hemiptera: Miridae), 1900-1980. U.S. Dep. Agric. Bibliogr. Lit. Agric. 30: 1-205.
- Hagel, G.T.. 1978. Lygus spp.: damage to beans by reducing yields, seed pitting and control by varietal resistance and chemical sprays. J. econ. Ent. 71: 613-615.
- Hanny, B.W., and C.D. Elmore. 1974. Amino acid composition of cotton nectar. J. Agric. Fd. Chem. 22: 476-478.
- Harper, F.R., and B. Berkenkamp. 1975. Revised growth-stage key for Brassica campestris and B. napus. Can. J. Pl. Sci. 55: 657-658.

- Hatfield, L.D., J.L. Frazier, and J. Ferreira. 1982. Gustatory discrimination of sugars, amino acids, and selected allelochemicals by the tarnished plant bug, Lygus lineolaris. *Physiol. Ent.* 7: 15-23.
- Hatfield, L.D., J. Ferreira, and J.L. Frazier. 1983. Host selection and feeding behavior by the tarnished plant bug, Lygus lineolaris (Hemiptera: Miridae). *Ann. ent. Soc. Am.* 76: 688-691.
- Hauschild, K.I., and B.L. Parker. 1976. Seasonal development of the tarnished plant bug on apple in Vermont. *Environ. Ent.* 5: 675-679.
- Heinrich, B. (ed). 1981. *Insect Thermoregulation*, John Wiley, New York.
- Holopainen, J.K. 1989. Host plant preference of the tarnished plant bug Lygus rugulipennis Popp. (Het., Miridae). *J. appl. Ent.* 107: 78-82.
- Johnson, C.G. 1969. *Migration and Dispersal of Insects by Flight*. Methuen, London.
- Kelton, L.A. 1975. The lygus bugs (genus Lygus Hahn) of North America (Heteroptera: Miridae). *Mem. ent. Soc. Can.* 95: 1-101.
- Kelton, L.A.. 1980. The plant bugs of the prairie provinces of Canada. Heteroptera: Miridae. In: *The Insects and Arachnids of Canada, part 8*. Biosystematic Research Institute (Ottawa), Publication 1703. 408 pp..

- Khattat, A.R., and R.K. Stewart. 1975. Damage by tarnished plant bug to flowers and setting pods of green beans. J. econ. Ent. 68: 633-635.
- Khattat, A.R., and R.K. Stewart. 1977. Development and survival of Lygus lineolaris exposed to different laboratory rearing conditions. Ann. ent. Soc. Am. 70: 274-278.
- Khattat, A.R., and R.K. Stewart. 1980. Population fluctuations and interplant movements of Lygus lineolaris. Ann. ent. Soc. Am. 73: 282-287.
- Lamb, R.J.. 1989. Entomology of Oilseed Brassicas. A. Rev. Ent. 34: 211-229.
- Lamb, R.J., and G.H. Gerber. 1985. Effects of temperature on the development, growth, and survival of larvae and pupae of a north-temperate chrysomelid beetle. Oecologia 67: 8-18.
- Lamb, R.J., and W.J. Turnock. 1982. Economics of insecticidal control of flea beetles (Coleoptera: Chrysomelidae) attacking rape in Canada. Can. Ent. 114: 827-840.
- Landis, B.J., and L. Fox. 1972. Lygus bugs in eastern Washington: color preferences and winter activity. Environ. Ent. 1: 464-465.

- Leigh, T.F., A.H. Hyer, J.H. Benedict, and P.E. Wynholds. 1985. Observed population increase, nymphal weight gain and oviposition non-preference as indicator of Lygus hesperus Knight (Heteroptera: Miridae) resistance in glandless cotton. J. econ. Ent. 78: 1254-1258.
- Luckmann, W.H., and R.L. Metcalf. 1982. The pest management concept. pp.1-31. In: Metcalf R.L. and W.H. Luckmann (Eds.), Introduction to Insect Pest Management. Wiley, New York.
- MacCreary, D. 1965. Flight range observations on Lygus lineolaris and certain other Hemiptera. J. econ. Ent. 58: 1004-1005.
- Mailloux, G., and N.J. Bostianan. 1988. Economic injury level model for tarnished plant bug, Lygus lineolaris (Palisot de Beauvois) (Hemiptera: Miridae), in strawberry fields. Environ. Ent. 17: 581-586.
- Malcolm, D.R. 1953. Host relationship studies of Lygus in south central Washington. J. econ. Ent. 46: 485-488.
- Mattson, W.J., and R.A. Haack. 1987. Role of drought stress provoking outbreaks of phytophagous insects. pp.365-407. In: Barbosa, P., and J.C. Schultz. (eds.): Insect Outbreaks. Academic Press, San Diego.

- McNeill, S., and R.A. Prestige. 1982. Plant nutritional strategies and insect herbivory community dynamics. pp.225-235. In: Proceedings of the 5th International Symposium on Insect-Plant Relationships. Pudoc, Wageningen.
- Mueller, A.J., and V.M. Stern. 1973. Lygus flight and dispersal behaviour. Environ. Ent. 2: 361-364.
- Mueller, A.J., and V.M. Stern. 1974. Timing of pesticide treatments on safflower to prevent Lygus from dispersing to cotton. J. econ. Ent. 67: 77-80.
- Painter, R.H. 1927. Some notes on the oviposition habits of the tarnished plant bug, Lygus pratensis Linn., with a list of host plants. A. Rep. ent. Soc. Ont. (1926) 57: 44-46.
- Phillips, J.H.H., and J.H. DeRonde. 1966. Relationship between the seasonal development of the tarnished plant bug, Lygus lineolaris (Beauv.) (Hemiptera: Miridae) and its injury to peach fruit. Proc. ent. Soc. Ont. 96: 103-107.
- Prokopy, R.J., and E.D. Owens. 1978. Visual generalist with visual specialist phytophagous insects: host selection behaviour and application to management. Entomologia exp. appl. 24: 409-420.
- Prokopy, R.J., and E.D. Owens. 1983. Visual detection of plants by herbivorous insects. A. Rev. Ent. 28: 337-364.

- Prokopy, R.J., R.G. Adams, and K.I. Hauschild. 1979. Visual responses of tarnished plant bug adults on apple. *Environ. Ent.* 8: 202-205.
- Purcell, M., and S.C. Welter. 1990. Degree-day model for development of Calocoris norvegicus (Hemiptera: Miridae) and timing of management strategies. *Environ. Ent.* 19: 848-853.
- Purseglove, J.W.. 1968. *Tropical Crops: Dicotyledons*. Longman, London.
- Ridgway, R.L., and G.G. Gyrisco. 1960a. Effect of temperature on the rate of development of Lyqus lineolaris (Hemiptera: Miridae). *Ann. ent. Soc. Am.* 53: 691-694.
- Ridgway, R.L., and G.G. Gyrisco. 1960b. Studies of the biology of the tarnished plant bug, Lyqus lineolaris. *J. econ. Ent.* 53: 1063-1065.
- Salt, R.W.. 1945. Number of generations of Lyqus hesperus Knt. and L. elisus Van D. in Alberta. *Scient. Agric.* 25: 573-576.
- SAS Institute, Inc. 1990. *SAS/Stat User's Guide, version 6, 4th Ed.*. pp.1686.
- Schotzko, D.J., and L.E. O'Keefe. 1989. Geostatistical discription of the spatial distribution of Lyqus hesperus (Heteroptera: Miridae) in lentils. *J. econ. Ent.* 82: 1277-1288.

- Scott, D.R. 1977. An annotated listing of host plants of Lygus hesperus Knight. Bull. ent. Soc. Amer. 23: 19-22.
- Shull, W.E.. 1933. An investigation of the Lygus species which are pests of beans (Hemiptera: Miridae). Idaho Agric. Exp. Stn. Bull. 11.
- Slaymaker, P.H., and N.P. Tugwell. 1982. Low-labor method for rearing the tarnished plant bug (Hemiptera: Miridae). J. econ. Ent. 75: 487-488.
- Snodgrass, G.L., W.P. Scott, and J.W. Smith. 1984. Host plants and seasonal distribution of the tarnished plant bug (Hemiptera: Miridae) in the delta of Arkansas, Louisiana, and Mississippi. Environ. Ent. 13: 110-116.
- Sokal, R.R., and F.J. Rohlf. 1981. Biometry, 2nd ed.. Freeman and Company, New York, 859 pp..
- Southwood, T.R.E.. 1978. Ecological methods with particular reference to the study of insect populations, 2nd ed. Chapman and Hall, London. 524 pp.
- Stern, R.F., R. van den Bosch, and T.F. Leigh. 1964. Strip cutting alfalfa for lygus bug control. Cal. Agric. 18: 4-6.
- Stitt, L.L. 1940. Three species of the genus Lygus and their relation to alfalfa seed production in southern Arizona and California. U.S. Dep. Agric. Tech. Bull. 741. 19pp.

- Strong, F.E. 1971. A computer generated model to simulate mating behavior of lygus bugs. J. econ. Ent. 64: 46-50.
- Strong, F.E., J.A. Sheldahl, P.R. Hughes and E.M.K. Hussein. 1970. Reproductive biology of Lygus hesperus Knight. Hilgardia 40: 105-147.
- Taksdal, G. 1963. Ecology of plant resistance to the tarnished plant bug, Lygus lineolaris. Ann. ent. Soc. Am. 56: 69-74.
- Thomas, P. 1984. Canola Growers Manual. Winnipeg: Canola Council of Canada.
- Tingey, W.M., and T.F. Leigh. 1974. Height preference of lygus bugs for oviposition on caged cotton plants. Environ. Ent. 3: 350-351.
- Tingey, W.M., T.F. Leigh, and A.H. Hyer. 1975. Lygus hesperus: growth, survival and egg laying resistance of cotton genotypes. J. econ. Ent. 68:28-30.
- Tingey, W.M., and E.A. Pillemer. 1977. Lygus bugs: crop resistance and physiological nature of feeding injury. Bull. ent. Soc. Am. 23: 277-287.
- Tugwell, P., S.C. Young, Jr., B.A. Dumas, and J.R. Phillips. 1976. Plant bugs in cotton: importance of infestation time, types of cotton injury, and significance of wild hosts near cotton. Arkans. Agric. Exp. Stn., Report Series 227. 24pp.

- Turnock, W.J., B. Timlick, and I. Wise. 1989. Lygus species attacking Canola in Manitoba. pp.137-143. In: Technical and Scientific Papers Presented at Manitoba Agri-Forum 1989.
- Weaver, N., and R.C. Thomas, Jr.. 1956. A fixative for use in dissecting insects. Stain Technol. 31: 25-26.
- Wheeler, A.G., Jr.. 1974. Studies on the arthropod fauna of alfalfa. VI Plant bugs (Miridae). Can. Ent. 106: 1267-1275.
- Wilson, R.L., and D.L. Olson. 1990. Tarnished plant bug, Lygus lineolaris (Palisot de Beauvois) (Hemiptera: Miridae) oviposition site preference on three growth stages of a grain amaranth, Amaranthus cruentus L.. J. Kans. ent. Soc. 63: 88-91.
- Young, O.P.. 1986. Host plants of the tarnished plant bug Lygus lineolaris (Heteroptera:Miridae). Ann. ent. Soc. Am. 79: 747-762.

Appendix 1: Degrees of freedom (d.f.), F values, and p values of the analysis of variance on the counts per sample of the three species of Lygus from the four seedings of oilseed rape in 1988 and 1989 (TABLE 1).

Year	species	d.f.	F value	p value
1988	<u>L. borealis</u>	3,9	2.90	0.090
1988	<u>L. desertinus</u>			
1988	<u>L. lineolaris</u>	3,9	21.40	<0.01
1989	<u>L. borealis</u>	3,12	4.77	0.020
1989	<u>L. desertinus</u>	3,12	41.83	<0.01
1989	<u>L. lineolaris</u>	3,12	20.29	<0.01

¹ For L. borealis and L. desertinus combined.

Appendix 2: Degrees of freedom (d.f.),
 F values, and p values of the analysis of
 variance on the times from seeding to
 the median catch of the adults of the
 three species of Lygus from the four
 seedings of oilseed rape in 1989
 (TABLE 5).

<u>Seeding</u>	<u>d.f.</u>	<u>F value</u>	<u>p value</u>
1	2,8	11.87	0.001
2	2,8	29.66	0.001
3	2,8	0.21	0.865
4	2,8	0.47	0.642