Seasonal Abundance, Damage Assessment and Economic Threshold of the Pea Aphid, *Acyrthosiphon pisum* (Harris), on Field Peas in Manitoba

by

George Alfred Maiteki

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A thesis submitted to the Faculty of Graduate Studies of
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Dedicated to my parents, Gertrude Kizza Nalongo and Henry Mukasa.

ABSTRACT

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Major Advisor: Dr. Robert J. Lamb

This study was conducted during the summers of 1981-1983. Populations of the pea aphid, *Acyrthosiphon pisum* (Harris), were sampled in pea plots at two locations. The effect of aphid feeding on whole plants and reproductive structures was studied by artificial infestations in field and sleeve cages, respectively. The economic threshold was determined by manipulation of aphid densities using different insecticide regimes in field plots.

Natural infestations started in late May or early June when the crop was at the seedling growth stage but populations remained at low levels throughout June. Populations started to increase in early July to a single peak each year, in late July or early August when the crop was at the pod maturity growth stage. Differences in peak populations at the two locations were not as great as differences among years. Sharp population declines occurred soon after each peak as the crop matured and dried.

Aphid feeding on pea plants reduced all yield parameters measured except protein content of the seeds. Yield reductions depended on aphid density and crop growth stage at time of infestation. However, feeding on the vegetative stage alone did not affect yield. Feeding during flowering and pod filling stages was very detrimental to yield. Feeding studies on reproductive structures revealed that flowers, young and enlarged flat pods were the most susceptible to aphid damage.

The timing of insecticide application was important in the control of pea aphids. Early application of insecticide was ineffective for protecting yield because aphid populations rebound in two to three weeks, while late application permitted damage to young and enlarging pods. The best time to apply insecticide was when 50-75% of the crop was in bloom, and with pods beginning to form. The economic threshold was variable from year to year due to variations in control costs, product price and yield potential of the crop. The economic threshold for the three seasons was calculated to be 8.9-12.2 aphids/sweep.

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INTRODUCTION

1.1. The Problem.

Field peas, _Pisum sativum_ (L.) are grown in Canada for the manufacture of pea soup, for export and for animal feed. The amount grown varies each year, but Manitoba has remained the major pea producing area, contributing 65 percent to the total Canadian pea production (Anonymous 1979, 1984; Ali-Khan and Zimmer 1980). The area under field peas has been increasing since 1945 in Manitoba, being 6,070 ha in 1945 and 44,500 ha in 1982 (Anonymous 1979, 1982). This trend in pea production is likely to continue (Anonymous 1979, 1984).

In Manitoba, the crop is grown in the Red River Valley. It is seeded in May and harvested in August. Each year, the crop is invaded by the pea aphid, _Acyrthosiphon pisum_ (Harris), which migrates from winter hosts, probably alfalfa and perennial wild legumes since these have been reported as winter hosts in other areas (Eichmann 1940; Swenson _et al_. 1954; Cooke 1963). The aphid populations soon increase and sometimes reach densities which cause pea growers to use insecticidal control. The spraying is costly since it must be done from the air to prevent crop damage that would occur if ground applicators were driven in the fields.

Spraying of insecticides is the only recommended control practice. It is conducted based on recommendations such as: "The pea crop should be watched closely and sprayed as soon as a marked increase in aphid populations is noted" (Anonymous 1977, 1984), or "If white patches appear on pea foliage, severe damage can be expected" (Anonymous 1983). Such statements are vague, and can lead to prophylactic measures or insurance treatments because of the risks and uncertainties involved (Glasgow 1939; Hillebrandt 1960; Carlson 1970; Headley 1972). When information on yield versus pest density is not available, decision making in pest control is subjective, often leading to pesticide abuse or underutilization (Stern 1973; Cothran and Summers 1974).

There are numerous reports on the effect of the pea aphid on crops, particularly alfalfa, but very few studies of its effects on peas. The studies which have been reported are based on laboratory experiments using young pea plants (e.g., Barlow _et_ _al_. 1977; Barlow and Messmer 1982). No studies have attempted to assess the types and extent of damage caused by the pea aphid on field peas under field conditions; nor has there been any published research on the densities of pea aphids in Manitoba field peas. Thus, there is no reliable information which extension entomologists or farmers can use as a basis for making a decision on the necessity or timing of an insecticide application.

1.2. Objectives.

The study was conducted with the following objectives:

i. To describe the changes in pea aphid densities in relation to crop phenology.

ii. To assess the types of damage caused by aphids feeding on the crop.

iii. To assess the economic significance of these types of damage especially as regards yield reduction.

iv. To determine an economic threshold for pea aphid damage.

Several advantages could accrue from the results of this study.

i. Some knowledge of the aphid's seasonal population growth in relation to crop phenology would be obtained. This knowledge is useful in planning pest control programs since it enables one to apply control measures at a time when pest numbers are high or increasing.

ii. Damage assessment studies could lead to the determination of the critical stage of crop growth at which significant damage occurs, thus helping in planning timely control programs.

iii. An economic threshold would enable farmers to apply insecticides only when necessary, thus resulting in preservation of the environment, reduced crop production costs and increased farm revenue.

1.3. Approaches and Thesis Organization.

The results reported in this thesis are from field experiments carried out during the summers of 1981, 1982 and 1983. Population studies were done at the Agriculture Canada Research Station, Winnipeg, and at its field station at Glenlea. Damage assessment studies were done in field cages at the Agriculture Canada Research Station, Winnipeg.

Economic threshold studies were done by manipulating aphid populations using different insecticide spray regimes in plots at Glenlea.

The thesis is written in chapters, each covering a separate aspect of the research. Chapter II is a review of the pertinent literature, Chapter III describes the experimental program and is written in four sections in a style suitable for publication as a series of scientific papers, Chapter IV provides a general discussion and Chapter V presents conclusions. In Chapter III, population studies are reported in Section 1. Experiments on feeding damage are reported in Sections II and III while Section IV covers the experiments for determining the economic threshold.

Chapter II

LITERATURE REVIEW

2.1.1. Pea Aphid Distribution, Damage and Economic Importance.

The pea aphid, *Acyrthosiphon pisum* (Harris), is found on every continent of the world except Antarctica (Hill 1975). It was first described in Great Britain in 1776 (Harper *et al*. 1978), and was accidentally introduced to North America from Europe on infested clover and peas (Folsom 1909). It was unknown in North America before 1878 but since its introduction, it has become widely distributed and appeared as a crop pest for the first time in 1899 (Folsom 1909; Davis 1915; Campbell 1926). It has become a pest on crops such as field peas, *Pisum sativum* (L.), and alfalfa, *Medicago sativa* L., grown for seed and hay. Davis (1915), Campbell (1926) and Eastop (1971) list the known hosts while a review of its pest status in Canada is given in Beirne (1972).

The types of damage caused to plants by aphids have been reported by Harvey and Wilson (1962), Apablaza and Robinson (1967), Harper (1973), A'Brook (1974), Wratten (1975), Wratten and Redhead (1976), Ba-Angood and Stewart (1980a & b), Keickhefer and Kantack (1980), Straub and Boothroyd (1980), Stern *et al*. (1980), Halbert *et al*. (1981) and many others. The damage is a result of one or a combination of the following.

i. Withdrawal of plant sap during feeding.

ii. Toxic action of salivary secretions injected during feeding.

iii. Virus transmission.

iv. Deposition of honeydew on plant surfaces.

The pea aphid usually infests the growing tips of plants. These are areas of active cell division and growth, where the concentrations of sugars, amino acids and auxins are highest (Maxwell and Painter 1962a; Bardner and Fletcher 1974). Both nymphs and adults of the pea aphid pierce the plant tissue and suck the sap from terminal and flower buds, leaves, stems and pods. As the aphids feed on the plants, they remove sugars, amino acids and minerals (Auclair 1958, 1963; Harper and Kaldy 1978), and plant growth hormones (auxins) such as 3-indole acetic acid (IAA), 3-indole butyric acid (IBA) and indole pyruvic acid (IPA) (Maxwell and Painter 1962a & b). Pea aphid feeding is also known to reduce the concentration of carotene, protein and soluble carbohydrate in the plant (Harper and Lilly 1966; Harvey _et al_. 1971; Kindler _et al_. 1971; Barlow _et al_. 1977).

The plant nutrients and auxins are necessary for normal plant growth, flower initiation and formation, seed set and seed filling (Audus 1963; Leopold 1963; Street and Opik 1970). Their removal deprives the plants of these materials, and aphid feeding also creates extra sinks for the products of photosynthesis, thus interfering with the normal partitioning of such materials among various plant parts (Mittler and Sylvester 1961; Wratten 1975, 1978; Wratten and Redhead 1976; Petitt and Smilowitz 1982). As a result, plant growth, flowering, the number of seeds and mean seed weight are reduced, thus affecting yields of seed and dry matter. Pea aphid feeding is also known to reduce the nitrogen fixing ability of pea plants (Sirur and Barlow 1984). In severe infestations, aphid feeding can result in yellowing of leaves and death of plants.

Damage to plants by aphids and other sap feeders can also be caused by toxic salivary secretions and plant disease viruses. The saliva of pea aphids is considered relatively non-toxic (Mittler and Sylvester 1961), but the species is known to vector 20 plant viruses (Kennedy *et al*. 1962). However, it is not as effective in transmitting viruses as the green peach aphid, *Myzus persicae* (Sulzer) which is known to transmit 108 different plant viruses (Lamb 1974). The principal viruses transmitted by the pea aphid are alfalfa mosaic, alsike clover mosaic, bean yellow mosaic, pea enation mosaic, pea mosaic, pea streak and red clover vein mosaic (Harper *et al*. 1978).

The excrement of aphids, honeydew, contains amino acids and sugars (Auclair 1958, 1963). It is produced in large quantities and often covers the leaves, twigs and fruits of the host plants. Sooty mold and fungal diseases frequently develop on the sticky excrement and hinder assimilation by the leaves (Schmutterer 1969; Bardner and Fletcher 1974). The damage which results from the mold and diseases can be enormous especially if the plant products, such as fruits, on which honeydew is deposited are sold on their appearance. Honeydew excreted by pea aphids does not stick readily to plant surfaces (Auclair 1958), probably because it has a relatively lower sugar concentration than honeydew of other aphid species (Mittler and Sylvester 1961).

The pea aphid has been of substantial economic importance. In the United States, it damaged peas valued at $3 and $4 million in 1899 and 1900, respectively (Folsom 1909). The aphid destroyed practically the entire pea crop in Quebec and Atlantic Provinces in 1899 and 1900 (Beirne 1972). In southern California, it forced many pea growers to abandon their crops in 1921, resulting in a 50-70% reduction in total crop production (Campbell 1926). Control of pea aphids with insecticides increased yields of alfalfa hay up to 125% (Franklin 1953), and its damage was responsible for losses in alfalfa production of about $60 million a year in the United States (Carnahan _et_ _al_. 1963). Harper and Kaldy (1982) reported that the pea aphid affected hay yield by significantly reducing the mean heights of alfalfa plants by 45%, the dry weight by 44%, the green weight by 38% and the fibre content by 13%. It is also known to reduce winter hardiness of alfalfa (Folsom 1909; Davis 1915; Harper and Lilly 1966; Harper and Feryman 1979). Control of the pea aphid with parathion sprays reduced the incidence of pea enation mosaic and increased yield of shelled peas by 12.8-85.9% (Davis _et_ _al_. 1961). On faba beans, transmission of bean yellow mosaic by the pea aphid caused 59-69% reduction in yield (Frowd and Bernier 1977). These reports indicate the importance of the pea aphid as a pest and vector of virus diseases on cultivated legumes. However, the extent of damage depends on crop growth stage at time of infestation.

2.1.2. Crop Growth Stage and Pea Aphid Damage.

For most crop plants, susceptibility to insect damage varies with the growth stage of the plants at the time of infestation. A common pattern is that of cereals such as wheat or barley in which individual plants are most vulnerable immediately after germination, for they cannot survive injuries that an older plant would tolerate. For example, Wells and McDonald (1961) found that little damage occurred when the corn leaf aphid, *Rhopalosiphum maidis* (Fitch), attacked barley that had advanced to late growth stages whereas severe damage occurred when the plants were infested during the early growth stages. Apablaza and Robinson (1967) found that barley seedlings were killed by the greenbug, *Schizaphis graminum* (Rondani), whereas plants infested 65 days post-seeding survived. Twenty aphids, *Rhopalosiphum padi* L. and *Macrosiphum avenae* (Fabricius), per tiller of barley significantly reduced yield when they were introduced at the beginning of ear emergence, but not at the milky ripe stage (Ba-Angood and Stewart 1980b). Early infestation of potato plants by *M. persicae* resulted in foliar damage and more permanently reduced the production capacity of the plants than when infestation occurred during late growth stages (Pettit and Smilowitz 1982). Bardner and Fletcher (1974) pointed out that older plant tissues are usually tougher, unsuitable to insects for feeding or oviposition and are less easily injured than young ones. However young plants are capable of compensating for the damage by regrowth later in the season provided earlier damage does not result in death of the plants.

Little information has been published on the relationship between stage of crop growth and damage by pea aphids. In laboratory studies using young pea plants, Barlow et al. (1977) and Barlow and Messmer (1982) reported that severe attack at the seedling stage of growth by pea aphids is detrimental to pea growth. They also concluded that for future growth and productivity, it is important that pea plants remain free of severe aphid attack while at the seedling growth stage. These authors did not test later growth stages and it would be interesting to know the amount of damage caused at such stages. However, from the literature on the damage caused to plants at different growth stages by other aphid species, it can be expected that a similar pattern applies to the damage caused by pea aphids.

2.1.3. Pea Aphid Density and Damage to Peas.

The relationship between density of pea aphids and damage to peas has been investigated in very few cases, and only in laboratory studies using young pea plants. An initial infestation density of 5 aphids per plant reduced plant weight by 4.7% whereas a 63.9% reduction was observed when the initial infestation was 50 aphids per plant (Barlow et al. 1977). These reductions were observed after 11 days of aphid feeding. When 9 day old pea seedlings were infested with aphids, the amount of damage depended on initial density of the infestation. With 25 aphids per plant, the net relative growth rate fell by 36% after 10 days feeding whereas 50 aphids per plant during the same period reduced the growth rate by 118% (Barlow and Messmer 1982). These authors also reported a 32% reduction in surface area of leaves by 25 aphids per plant over 10 days and twice as much reduction during the same period when the inoculum was 50 aphids per plant. The observed reduction of relative growth rate was attributed to the reduction of the photosynthetic surface area. The relevance of these data to peas growing under natural conditions are unknown.

2.2. Life History and Biology of the Pea Aphid.

The life cycle of aphids is complex, involving a series of different forms, the transition from one form to another being influenced by changes in the environment and internal factors (Lees 1966; Hille Ris Lambers 1966). In most aphid species, there is a complete cycle (holocycle) in which a series of parthenogenetic generations in the spring and summer is followed by a single annual sexual generation. Usually, sexual morphs are produced in late summer or autumn. They mate and the females lay eggs which overwinter. Life cycles involving continuous, year-round parthenogenesis (anholocycly) occur in the tropics and warmer areas of temperate regions (Blackman 1974; Dixon 1977). The pea aphid exhibits either holocycly or anholocycly, or a combination of both, depending on the enviromental conditions encountered in different regions (Cooke 1963).

On the basis of the life history observed in other temperate locations (Cooke 1963; Markula 1963, Campbell 1974), in Manitoba, _A. pisum_ is holocyclic and overwinters as eggs on alfalfa and perennial wild legumes (Figure 1). In the spring, the eggs hatch to give rise

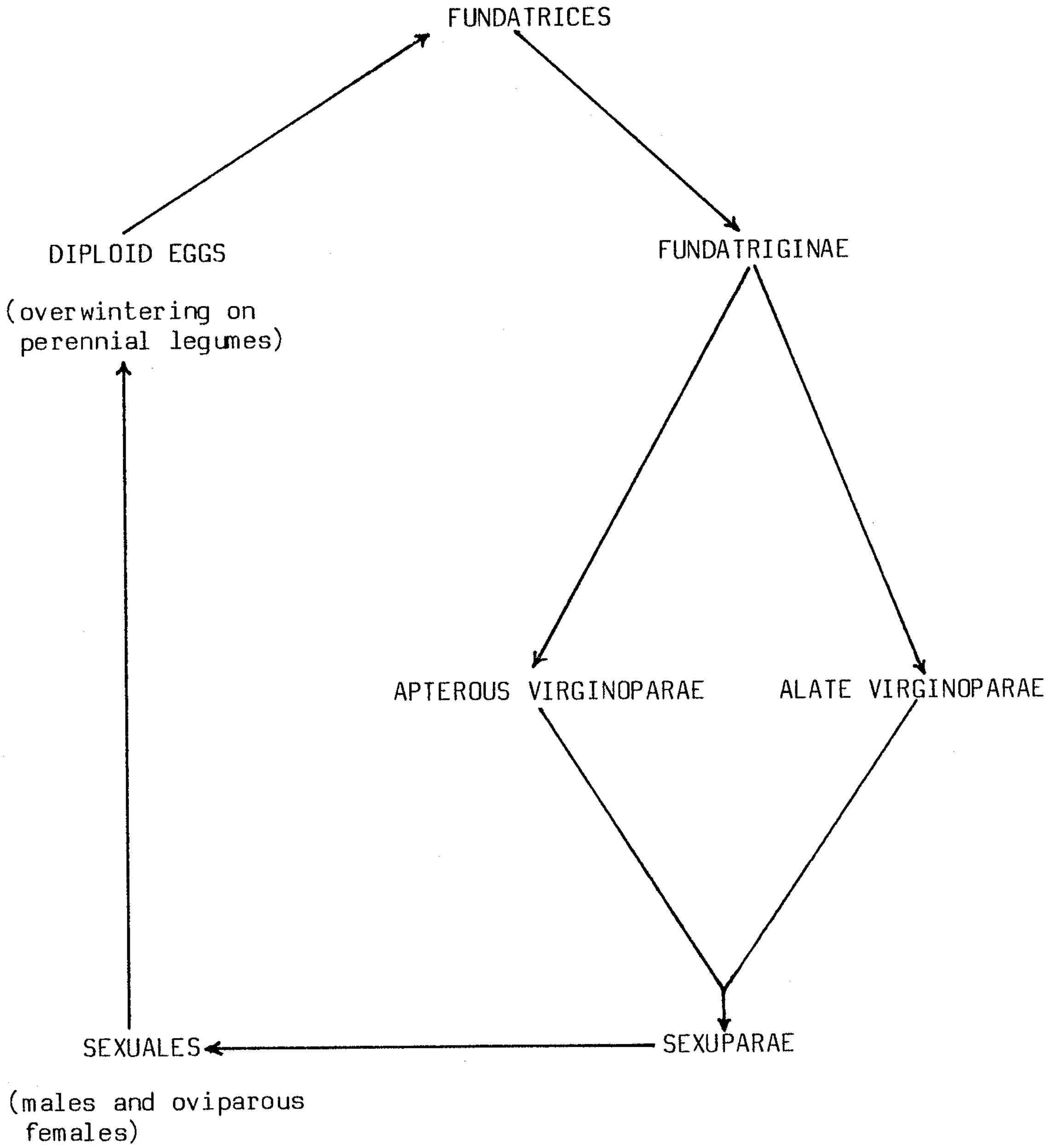


Figure 1. Life cycle of the pea aphid, Acyrthosiphon pisum (Harris) in temperate regions.

to a generation of wingless females (fundatrices). These feed on new growth, then give birth to offspring that develop into both winged (alatae) and wingless (apterae) viviparous parthenogenetic females. The winged females migrate and colonize summer hosts such as field peas. They give birth to more wingless females, which in turn give rise to further generations of both winged and wingless females throughout the summer. The apterous (wingless) viviparous females are the predominant form found on summer hosts. The winged aphids fly within and between fields throughout the summer months and colonize other plants, thus ensuring a wide distribution (Cooke 1963). In the late summer or fall, sexuales appear in a population in response to dropping temperatures and shortening day length (Kenten 1955; Lamb and Pointing 1972, 1975). After mating, they lay eggs on the leaves and stems of winter hosts and the annual cycle is complete.

Pea aphids may be present as apterous fundatrices, alate or apterous viviparous females, apterous oviparous females and alate or apterous males (Harper _et_ _al_. 1978). Both green and red pea aphids occur in Europe, but only the green form has been reported in North America (Markula 1963). Hille Ris Lambers (1947) gives a description of the various morphs of adults of the green form. The fundatrices have broadly oval bodies with short antennae and siphunculi. The apterous viviparous females have spindle shaped, rather slender bodies with long antennae, siphunculi and legs. Alate viviparous females are very much like apterous viviparous females except that the thorax is sclerotic; antennae, legs and siphunculi are brownish black. The oviparous females resemble the apterous viviparous females but their bodies are slightly yellowish, siphunculi are shorter, the cauda thinner and slightly blunt. The apterous and alate males have slender dark green bodies with short dark brownish antennae and siphunculi. There are four nymphal instars. The third and fourth instar of apterae are easily distinguished from alatae by the absence of wing buds (Cooke 1963; Campbell 1974).

Different aphid morphs play different ecological roles. The fundatrices, being from eggs laid after the sexual cycle in the previous season consist of diverse genotypes (Dixon 1977). They are the founders of the summer generations. The apterous viviparous females are highly prolific and as such, are producers and multipliers while the alate viviparous females, because of their ability to fly are dispersers and ensure escape from deteriorating host plants to colonize new habitats (Cooke 1963; Hille Ris Lambers 1966; Lees 1966). The sexual forms ensure genetic recombination, thus maintaining the genetic variability and fitness of future populations (Dixon 1977).

Many factors are known to affect aphid polymorphism. The effect of dropping temperatures and shortening daylength on the production of sexual forms has already been mentioned. Host plant condition and crowding are important in the production of winged pea aphids (Sutherland 1967, 1969a & b). As the plants mature, their nutritional quality deteriorates while crowding enhances physical contact between aphids, thus promoting wing development. However, the aphid's ability to respond to host plant condition and crowding may be modified by environmental variables such as temperature and photoperiod (Sutherland 1969b), some intrinsic factor within the aphid (Sutherland 1970) or maternal age effects (MacKay 1977; MacKay and Wellington 1975).

The length of the various phases of the life history and fecundity of A. pisum have been reported. The pre-reproductive period is 8-12 days and the average length of the reproductive period is about 15-20 days, but both may be longer at low temperatures (Cartier 1960; Sylvester and Richardson 1966; Murdie 1969a; Kilian and Nielson 1971; Frazer 1972; Siddiqui et al. 1973; MacKay and Wellington 1975, Campbell and Mackauer 1977). Longevity is generally about 30 days at temperatures around 20°C (Cartier 1960; Kilian and Nielson 1971; MacKay and Wellington 1975). The number of progeny produced during the life span of agamic females ranges between 60-95 (Campbell 1926; Harrington 1943; Kenten 1955; Siddiqui et al. 1973; MacKay and Wellington 1975; Campbell and Mackauer 1977). The apterous morphs develop faster, reproduce more but are shorter lived than alatae (MacKay and Wellington 1975; Campbell and Mackauer 1977).

Many factors are known to affect the biology of pea aphids. Temperature affects development, reproduction and longevity (Campbell 1926; Kenten 1955; Sylvester and Richardson 1966; Murdie 1969a & b; Kilian and Nielson 1971; Siddiqui et al. 1973; Campbell 1974; Campbell and Mackauer 1975, 1977; Hutchison and Hogg 1984). Temperatures between 19°-26°C encourage rapid development, increase fecundity but reduce longevity. Temperatures above 26°C or below 10°C reduce developmental rate, fecundity and can cause high mortality (Sylvester and Richardson 1966; Murdie 1969a & b). Adults reared at 10°C or 25°-28°C produce few undersized progeny which either grow into small sized adults or suffer high mortality (Murdie 1969a & b). Campbell

(1974), Campbell and Mackauer (1975, 1977), and Hutchison and Hogg (1984) reported that the lower and upper temperature threshold for pea aphid development was 2.7-5.5°C and 25-30°C, respectively. The optimum temperature for development and reproduction is between 10°C and 20°C (Kenten 1955; Siddiqui et al. 1973; Campbell and Mackauer 1977). The number of generations per year varies from 6 to 28 depending on the region of the world (Folsom 1909; Davis 1915; Campbell 1926; Harrington 1941; Markula 1963). Fewer generations per season occur in regions with low temperatures while in places like California where temperatures are high, up to 28 generations have been reported (Campbell 1926). There are no reports on the number of generations of the pea aphid in Manitoba. However, because of the lower temperatures and shorter growing seasons in Manitoba, the number of generations in a season would be expected to be substantially lower than in California.

Literature on the effect of age of the host plant on reproduction and survival of the pea aphid is limited. In laboratory experiments, Auclair (1966) found that pea aphids reared on young pea plants of cultivar Perfection grew faster, reproduced more and survived longer than those reared on old plants. That pea aphids performed better on young plants is not surprising since the nutritional quality of mature leaves is considerably lower than that of seedlings or actively growing shoots (Zimmermann 1960; Carr and Pate 1967). Similar performances on young plants have been reported for other aphid species e.g. the English grain aphid, Sitobion avenae (F.), (Watt 1979) and the bird cherry oat aphid, R. padi, (Leather and Dixon 1981). Another factor of importance to development and fecundity is crowding. It has been shown to result in reduced adult size and weight, which in turn results in reduced fecundity (Murdie 1969a & b).

2.3. Population Dynamics of the Pea Aphid.

The dynamics of pea aphid populations have been studied primarily in alfalfa and to a lesser extent in peas (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971; Campbell 1974; Frazer and Gilbert 1976). In perennial alfalfa, the population pattern is characterized by a rapid increase to a peak in late spring followed by a gradual or rapid decline to lower densities throughout the summer and then another rapid increase to a second peak in late summer or early fall (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971). The magnitude and relative heights of the peaks within seasons vary from year to year (Dunn and Wright 1955) or place to place (Smith and Hagen 1966). In pea fields seeded at different periods of the year, aphid populations are characterized by a gradual increase to a peak in early summer on early planted peas followed by a corresponding decline in mid-summer and then another gradual increase to a second peak in late summer or early fall on late planted peas (Dunn and Wright 1955; Cooke 1963). The relative heights of the peaks within seasons may be regular from year to year (Dunn and Wright 1955) or irregular (Cooke 1963).

Variable rates of increase in numbers of pea aphids from season to season or place to place have been reported. For example, aphid populations in alfalfa in late spring, 1948 and early fall, 1949 increased in two weeks from 0 to about 6,000 aphids/25 sweeps and from just above 0 to 38,000 aphids/25 sweeps, respectively, (Dunn and Wright 1955). In pea fields, aphid populations increased from 1 to 14 aphids/plant tip in two weeks in early summer (Dunn and Wright 1955). Peak populations ranging from 0.47 to 22.35 aphids/tip in alfalfa fields and rates of population increase ranging from 0.07 to 3.40 aphids/tip/day have been reported (Cooke 1963). The same author reported that aphid populations in pea fields rose from 6 to over 40 aphids per plant tip in 10 days. Pea aphid populations rose in 3 weeks from just under 1 aphid/stem to 65 aphids/stem in the Central San Joaquin Valley and yet during the same period, aphid numbers did not reach a density of 1 aphid/stem in the South San Joaquin Valley (Smith and Hagen 1966).

The individual or combined effects of physical factors such as heavy rains, strong winds, high humidity and temperature extremes may influence aphid populations (Folsom 1909; Campbell 1926; Dunn and Wright 1955; Cooke 1963; Campbell 1974). Heavy rains and strong winds wash or shake the aphids off the plants, thus killing or disturbing them, resulting in reduction of aphid populations (Dunn and Wright 1955; Cooke 1963). The direct effects of temperature on the biology of the pea aphid have been mentioned. The influence of these effects on populations of pea aphids is implicit. Temperature can also indirectly affect pea aphid populations through its effect on disease development. Moderate temperatures (10-15°C) during periods of high humidity may encourage disease development in aphid colonies (Cooke 1963).

Harvesting practices, especially in alfalfa fields, can cause significant mortality of pea aphids (Dunn and Wright 1955; Cooke 1963; Campbell 1974). In peas grown for seed, harvesting is done when the crop is dry and it is unlikely that such a practice has an influence on aphid populations.

Biotic factors such as parasites, predators and pathogens are known to affect populations of pea aphids (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Tamaki *et al*. 1969, 1970; Pass and Parr 1971; Campbell 1974; Stary 1974; Stary *et al*. 1980; Neuenschwander *et al*. 1975; Frazer and Gilbert 1976; Frazer *et al*. 1981). The important parasites include *Aphidius smithi* Sharma and Subba Rao, *Aphidius ervi* Haliday and *Praon pequodorum* Viereck. *A*. *ervi* and *P*. *pequodorum* commonly parasitize pea aphids in Manitoba, the former being predominant (H.G. Wylie and F.O. Matheson, Agriculture Canada Research Station, Winnipeg, Personal Communication). Parasites affect aphid populations by reducing fecundity, increasing mortality and "harassing" and dispersing aphid colonies (Hagen and Van den Bosch 1968; Tamaki *et al*. 1969; 1970).

The important predators include Coccinellid beetles such as *Coccinella trifasciata perplexa* Mulsant, *Coccinella trifasciata subversa* Leconte, *Coccinella udecimpunctata udecimpunctata* L., *Coccinella californica* Mannerheim, *Hippodamia convergens* Guerin- Meneville, *Hippodamia tridecimpunctata* L., *Hippodamia sinuata* Mulsant and *Hippodamia quinquesignata punctulata* LeConte (Cooke 1963; Smith and Hagen 1966; Frazer and Gilbert 1976; Frazer *et al*. 1981). Syrphid flies, lace wings and various spiders are also predators of pea aphids

(Cooke 1963; Frazer *et al*. 1981). The syrphid flies include *Syrphus opinator* O.S., *Syrphus cylindrica* (Say), *Sphaerophoria robusta* Cur., *Melanostoma obscurum* (Say) and *Metasyrphus meadii* Jones (Cooke 1963). The thirteen spotted lady beetle, *H. tridecimpunctata* L. appears to be a significant mortality factor of pea aphids in Manitoba (Batulla 1983), although the importance of other species cannot be ruled out. Both the adults and larvae of beetles and spiders, and larvae of syrphid flies and lacewings capture and eat aphids (Cooke 1963; Frazer and Gilbert 1976; Frazer *et al*. 1981), and the searching movement of the beetles can trigger a drop reaction by adult aphids, thus disturbing aphid colonies and their feeding (Frazer and Gilbert 1976; Frazer *et al*., 1981). Pathogens in the genus *Entomophthora* cause diseases in aphids (Hagen and Van den Bosch 1968).

Maturation of the host plant is known to reduce fecundity and developmental rates of pea aphids (Auclair 1966; Murdie 1969a, b) and influences the production of alate offspring (Sutherland 1967, 1969b). As the plants mature, their nutritional quality deteriorates and they become unsuitable for the aphids. The reduction in fecundity and development, and the production of alate offspring which leads to mass migration, can cause rapid population declines (Dunn and Wright 1955; Campbell 1974).

The number of immigrant alatae colonizing the host plants early in the season can determine the level to which the population will grow. Campbell (1974) found that the larger the number of immigrant alatae colonizing a field, the greater was the density of aphids attained later in the season. Immigrants flying into the field later in the season can also add to the local population and augment its reproductive rate and population increase (Cooke 1963; Campbell 1974).

While the factors mentioned can affect aphid populations, the regulation of these populations is complex. No single factor can be singled out to explain the seasonal patterns and maximum densities reached. Indeed, Cooke (1963), Pass and Parr (1971), Frazer and Gilbert (1976) and Frazer _et al_. (1981) concluded that single factors such as natural enemies alone, cannot control pea aphid populations. Nevertheless, the individual or combined effects of the factors have all been suggested to influence pea aphid populations.

2.4. Economic Injury and Economic Threshold

i. Definitions

The concept of integrated control, as first formulated by Stern _et al_. (1959), stresses the importance of accurate correlation of pest density with economic losses in situations involving decisions to apply control measures. Stern _et al_. (1959) proposed two critical population levels to categorize the decision process, the higher of these was termed the economic injury level (EIL) and the lower, the economic threshold (ET). They defined the economic injury level as "the lowest populaton density that will cause economic damage", the economic damage being "the amount of injury which will justify the cost of artificial control measures." The economic threshold, sometimes referred to as "action threshold" (Chant 1966; Cancelado and

Radcliffe 1979a, b) was defined as "the density at which control measures should be initiated to prevent an increasing pest population from reaching the economic injury level." The definitions required determination of the ET at a point which provides sufficient time for control measures to be applied before the EIL is reached and exceeded. This requirement implied that both the EIL and the time when it occurs must be known before an ET can be determined.

Since the proposal of these terms, economic thresholds have been defined in a number of ways. For example, Edwards and Heath (1964) stated that a pest population has reached the economic threshold when the population is large enough to cause damage valued at the cost of practical control. Beirne (1966) suggested that the economic threshold is a critical level of damage above which damage will not be tolerated. He continues to say that damage above this critical level causes the pest responsible to be labeled as a damaging pest and consideration is given or action is taken to try to abate the damage. The National Academy of Sciences (1969) defined the economic threshold as "the level at which damage can no longer be tolerated and, therefore, the level at or before which it is desirable to initiate deliberate control activities." Headley (1973) defined it as "the pest population that produces incremental damage equal to the cost of preventing that damage." Recently, Poston _et_ _al_. (1983) defined the economic threshold as "that decision level chosen such that there is little likelihood that the real management system might inadvertently permit the pest population to exceed the EIL".

An examination of the definitions indicates that some of them are incomplete as they seem to neglect the economic considerations in pest control decisions as outlined in the original definitions of Stern et al. (1959). Among the various definitions, only those by Edwards and Heath (1964) and Headley (1973) consider the economic aspects in determining an economic threshold. These definitions offer a straight forward determination of economic thresholds. According to the definitions, the economic threshold concept demands that for any control measure to be justifiable, the value of the yield increase resulting from control measure must be equal to or greater than the cost of control. The pest population at which such yield increases are realized after application of a control measure is the economic threshold.

ii. Determination of Economic Thresholds.

Although Stern et al. (1959) were the first to propose the terms "Economic injury levels " and "Economic threshold", the idea of establishing a relationship between pest density and potential crop damage is an old one. Shotwell (1935) designed a rating system of 5 categories based on grasshopper density to relate damage to pest density. The categories were: normal, light, moderate, heavy and very heavy. The threshold density in the moderate category was about 15 grasshoppers/yd^2 and at this density, approximately 40% of the land in the infested area could suffer some loss if grasshoppers were not controlled. The density was determined by counting free-living grasshoppers as the observer walked through an infested area.

Insect infestations can result in yield reduction, quality change and delay in maturity of a crop, thus reducing crop value (Bardner and Fletcher 1974). In some instances, insect infestations can result in regulatory restrictions on marketable crop products, also resulting in reduced crop value. Such restrictions demand that no product with insects, insect products or damage scars will be acceptable for sale (Stern 1966). Changes in crop value that are a consequence of a pest may be associated with a certain pest density through past experience, and the pest density is often established as an economic threshold (Stern 1966). Such thresholds have no experimental basis for their determination and are termed "nominal thresholds" (Poston et al. 1983). Poston et al. (1983) pointed out that the majority of existing thresholds probably fit into this category.

Stone and Pedigo (1972) integrated control cost, marketing and yield data with insect feeding data to determine the economic injury level of the green cloverworm, Plathypena scabra (F.), on soybean. Insect feeding data were obtained by caging individual larvae on leaves and then determining the leaf area consumed per insect. The relationship between yield and damaged leaf area was determined from previous studies of simulated damage. The amount of damage which would result in a reduction in yield equivalent to the cost of control was then calculated. This value was then divided by the amount of leaf area consumed per insect to give the economic injury level. The method was termed the "Deductive approach."

Ogulana and Pedigo (1974) developed an empirical method which correlates pest density directly with yield. The method involves artificially infesting plants with variable densities of the pest and determining the yield at each density. Variable densities of the pest can also be obtained by manipulating natural populations using different insecticide regimes (e.g., Cancelado and Radcliffe 1979b; Ferro et al. 1983) or natural enemies (e.g., Cancelado and Radcliffe 1979a). Once the yield obtained at each pest density is known, a regression model for the relationship of yield versus pest density is determined.

Such relationships may be linear or non-linear (Poston et al. 1983), but, often a linear relationship is adopted because of its simplicity. Ogulana and Pedigo (1974) used a linear relationship in which yield was related to pest density by the equation:

$$Y = a + bX$$

where Y = expected yield at a particular pest density.

a = Y intercept, a constant representing yield with no insect infestations.

b = Slope of the regression line, a parameter representing proportionate injury per individual insect.

X = the number of insects per sample unit.

The economic injury level (EIL) was calculated by the equations:

EIL = Gain threshold (kg/ha)/b, the slope of the regression line.

where Gain threshold (kg/ha) = Control costs (\$/ha)/Product price (\$/kg).

Ba-Angood and Stewart (1980b) developed a formula for calculating the economic threshold (ET) from the economic injury level. The formula requires knowledge about growth rate of the insect population and the number of days required for preparation of control measures.

The economic threshold was calculated by the equation:

Economic threshold (ET) = EIL-(rNxdt)

where EIL is as before

rN = the insect population growth rate per day.

dt = number of days required for preparation of control measures.

Cost-benefit analysis has also been used to determine economic thresholds (e.g., Cancelado and Radcliffe 1979b; Grafel 1982; Ferro *et al*. 1983). The method involves manipulation of pest numbers using different insecticide regimes and then calculating the yield benefits associated with each regime and pest density prior to insecticide application. The density at which maximum benefits are realized is taken as the economic threshold. Thresholds determined by the deductive approach, empirical method and cost-benefit analysis are based on experimental evidence on the relationship between the damage potential of the pest, crop market value, control costs and potential crop yield. These types of thresholds are termed "simple thresholds" (Poston *et al*. 1983).

Poston *et al*. (1983) suggested another method of determining thresholds. The method involves determination of thresholds on the basis of the total production system present on the farm and incorporation of variabilities in economic, weather and stress factors which occur from season to season. These authors termed such thresholds as "comprehensive thresholds" and pointed out that such thresholds are a goal yet to be attained.

iii. Determination of Economic Thresholds for Aphids.

There are few cases where economic thresholds have been determined experimentally, but many nominal thresholds have been reported for aphids. Examples include: 1 *M. persicae* per four beet plants in Britain (Hull and Heathcote 1967), 25-30 aphids (*R. padi* and *R. maidis*) per barley tiller in California (Stern 1967), 5-10 pea aphids (*A. pisum*) per pea plant in Quebec (Cartier 1968), and 50 pea aphids per pea plant in Manitoba (Ali-Khan 1980).

Two methods have been employed to experimentally determine economic thresholds for aphids. Some workers have used the Ogulana and Pedigo (1974) method, in field cages or spray plots. Examples of thresholds determined in field cages include: 8-16 aphids (*R. padi* and *M. avenae*) per barley tiller in Quebec (Ba-Angood and Stewart 1980b) and 25-30 aphids (*S. graminum* and *R. padi*) per wheat stem in South Dakota (Keickhefer and Kantack 1980). Cuperus *et al*. (1982) determined the economic threshold for the pea aphid on alfalfa by manipulating aphid densities in spray plots using different insecticide regimes and rates. They then used the Ogulana and Pedigo (1974) method to determine the relationship between yield and pest density, and reported the economic threshold at 1.2 aphids per stem or 70 aphids per sweep. Capinera (1981) selected naturally infested sugar beet plants in the field to determine the economic injury level for the bean aphid, *Aphis fabae* Scopoli. Aphid numbers on the plants were noted and the yield from these plants was regressed on insect numbers to determine the relationship between yield and pest density. He reported 2.5 aphid days as the economic injury level because the insecticide investment was recovered in this period of time. Presumably, this is also the economic threshold as per Edwards and Heath (1964) and Headley (1973) definitions.

Other workers have used cost benefit analysis to determine economic thresholds. Examples include: 30 apterous M. persicae per 105 potato leaves (Cancelado and Radcliffe 1979b), and over 40 aphids (Metopolophium dirhodum Wlk. and S. avenae) per ear and top leaf of wheat at milky ripe stage (Grafel 1982). Stern et al. (1980) used the same method to determine the economic threshold for the blue alfalfa aphid, Acyrthosiphon kondoi Shinji and Kondo, on alfalfa in California, but unfortunately, they did not establish a distinct threshold. They reported that 10-12 aphids per stem on new growth during January would later reduce alfalfa yields above control costs, and then that damage to new regrowth appeared to start at approximately 20 aphids/stem. Such inconsistencies limit the usefulness of thresholds since the decision maker has no basis for choosing between the values provided.

Each of the methods exhibits disadvantages. Nominal thresholds, although useful in reducing pesticide use (Poston et al. 1983), may be inaccurate and unreliable as they are not based on experimental evidence of economic damage. Use of field cages may not be respresentative of natural situations. The cages might improve conditions for plant growth, thus masking the effect of insects on the plants. Also insect numbers are difficult to maintain at the experimental densities, especially in prolific species such as aphids. This results in unrealistic numbers feeding on the plants. As a result yield losses may be over-estimated, or under-estimated, if there is high competition and mortality of insects due to presence of high densities. Under such circumstances, the relationship between yield and pest density, and thus the threshold, may be inaccurate.

Manipulation of insect numbers by use of insecticide spray regimes has the disadvantage of estimating potential damage from a single density estimate in the field. Also pest densities are difficult to estimate accurately, as the insect numbers obtained, especially when sweep nets are used, depends on the sampler and the conditions under which the samples are taken (Saugstad _et_ _al_. 1967). In addition, the pest density measured at a point in time relates most directly to the increment of damage inflicted at that time. At a later time, the pest population, and consequently, the corresponding damage increment will probably be different. To compare losses with control costs, accurate assessment must be made of losses at harvest . Poston _et_ _al_. (1983) pointed out that unless the yield component affected by insect injury and the impact of the affected components on yield are known, such assessment is difficult to accomplish.

When single plants are selected within a field (e.g. Capinera 1981), it is not valid to infer that the insects found on the plants were the sole cause of the observed yield loss. It is possible, for example, that the plants which are most severely infested are those which are least healthy for genetic or environmental reasons and are therefore particularly susceptible to infestation. They might therefore have had low yields even in the absence of infestation.

Although the methods for determining economic thresholds have been of benefit in quantifying yield losses associated with insect pests, they have several drawbacks and this has made the determination of an accurate economic threshold a goal yet to be attained. Indeed the National Academy of Sciences (1969) observed that it is difficult to determine economic thresholds because of the great number of factors involved, many of the important factors being economic and not readily available to, or assessable by, animal and plant scientists. Poston _et_ _al_. (1983) noted that these levels have proved notoriously difficult to measure because the primary determinants (i.e. control costs, crop market value, proportionate injury per individual pest and crop response to injury), are not simple constants but, rather, complex biological processes or economic variables which operate through space and time. This means that economic thresholds and injury levels are not static but, rather, are dynamic parameters varying from season to season with weather conditions, crop damage and yield responses, and economic variables.

Unfortunately, almost all economic thresholds that have been reported for aphids are static or nearly so. Although their determination has been based on the primary determinants, no consideration has been given to the variability which occurs from season to season in control costs, product prices, and weather changes as they affect potential insect damage and crop yield. The thresholds have been based on variables measured in a single season, and extrapolated to other seasons.

Headley (1972) pointed out that most economic thresholds ignore the distinction between private and social values and as such are of limited application. He further added that economic thresholds should be determined with a consideration of social benefits which accrue to the whole society following the implementation of the threshold. The social costs and benefits add another dimension to the concept of "comprehensive thresholds". While the thresholds so far determined have drawbacks, Poston *et al*. (1983) pointed out that "nominal" and "simple" thresholds are very useful and a step towards "comprehensive" ones.

CHAPTER III

EXPERIMENTAL PROGRAM

SECTION 1

Seasonal Abundance of the Pea Aphid, Acyrthosiphon pisum (Harris), (Homoptera: Aphididae) in Relation to Crop Phenology in Manitoba.

ABSTRACT

Populations of the pea aphid, *Acyrthosiphon pisum* (Harris), were sampled in pea plots through the summers of 1981, 1982 and 1983 at two locations. Aphids were first observed in late May or early June during the seedling growth stage but populations remained at low levels throughout June. Populations increased in early July during the flowering growth stage, and generally peaked in late July or early August when the plants and pods were maturing. Differences in density between the populations at the two locations were not as great as differences among years. Aphid populations decreased rapidly after populations peaked and as the plants started to senesce and dry.

1. Introduction

Since its introduction into North America prior to 1900, the pea aphid, Acyrthosiphon pisum (Harris), has become widely distributed over the continent and is a pest of peas, Pisum sativum (L.), and alfalfa, Medicago sativa L., grown for seed and hay (Folsom 1909; Davis 1915; Campbell 1926; Beirne 1972; Harper et al. 1978). Several studies have been done on the population dynamics of pea aphids in perennial alfalfa in Europe and North America (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971; Campbell 1974), and to a lesser extent in peas (Dunn and Wright 1955; Cooke 1963). These authors reported two peaks in population density, one in late spring or early summer and the other in late summer or early fall.

In Manitoba, there is a crop season of only 100 to 120 frost-free days (Dunlop and Shaykewich 1982), during which the pea aphid migrates from winter hosts and invades field peas. This is a much shorter season than is found in other areas where populations of pea aphids have been studied. This study describes the population growth of the pea aphid in an annual, short season crop, information which is essential for designing a pest management program. Aphid populations were sampled in experimental plots and the growth stages of pea plants were determined through the growing season to enable a description of aphid populations in relation to crop phenology.

2. Materials and Methods

The studies were conducted at the Agriculture Canada Research Station, Winnipeg, hereafter referred to as Winnipeg, and at its field station at Glenlea during the summers of 1981, 1982 and 1983. Field peas (cv. Century) were seeded in 10 x 10m plots in 1981 and 1982, and in 10 x 30m plots in 1983. The fields in which the experimental plots were located at Glenlea had been treated with Treflan granular herbicide and fertilized with 16:20:0 NPK. Seeding was done with a Bolens continuous seeder which seeded four rows at a time, the rows being approximately 30cm apart. There were 33 rows in the small plots and 100 rows in the large plots. Glenlea seedings were done on 11 May 1981, 13 May 1982 and 16 May 1983, while those at Winnipeg were done the following day. After germination, the rows were numbered to enable random sampling. Weeds were controlled by hand hoeing.

Sampling was initiated 10 to 15 days after planting and was done at weekly intervals through each growing season. On each sampling occasion, 15 rows in 1981 and 1982, and 20 rows in 1983, were randomly selected from the entire plot. From these rows, whole plants (all plant parts above ground) were examined during the first few weeks of each season but as the plants grew taller and bushier, tip samples (the uppermost 20 cm of a stem) (Gray and Schuh 1941) were taken. Two hundred randomly selected whole plants or 50 plant tips were sampled in 1981, 150 samples in each category in 1982, and 150 whole plants or 100 plant tips in 1983. The first plant or plant tip in each row was taken as a starting sample. Random samples within a row were then obtained by using a 1m stick and sampling the plant or plant tip at or nearest the tip of the stick. An approximately equal number of samples was taken from each row on each sampling occasion.

Whole plant samples were examined and any aphids present were recorded in situ. Tip samples were shaken and cut over an enamelled metal tray to minimize losses of adult aphids which often drop off the tips, and were individually stored in plastic bags on ice to minimize aphid reproduction (Campbell 1974). Any aphids in the tray were transferred to the appropriate bag using a moist camel hair brush. Insects were counted in the laboratory usually on the same day. In 1981, the number of winged and non-winged adults and total number of nymphs were recorded. Similar records were kept in 1982 but the nymphs were categorized as winged, those with apparent wing buds (Cooke 1963; Campbell 1974), or non-winged nymphs. In 1983, the non-winged nymphs were categorized as large non-winged (mostly third and fourth instars), and small non-winged nymphs, but the other categories were recorded as in the previous years.

Stages of plant growth were determined in the plot at Winnipeg in 1983. Ten plants were randomly selected on each day of aphid sampling and the growth stages were determined by adapting the methods used in soybeans (Fehr and Caviness 1977; Fehr _et_ _al_. 1971), to field peas.

Also in 1983, a farmer's field with plants at the same growth stage as those in experimental plots was selected and 100 plant tips were sampled on three occasions to enable comparison of field populations with those in experimental plots.

Weather records during the study period were obtained from Climatological Stations at Glenlea and Winnipeg International Airport for Glenlea and Winnipeg, respectively.

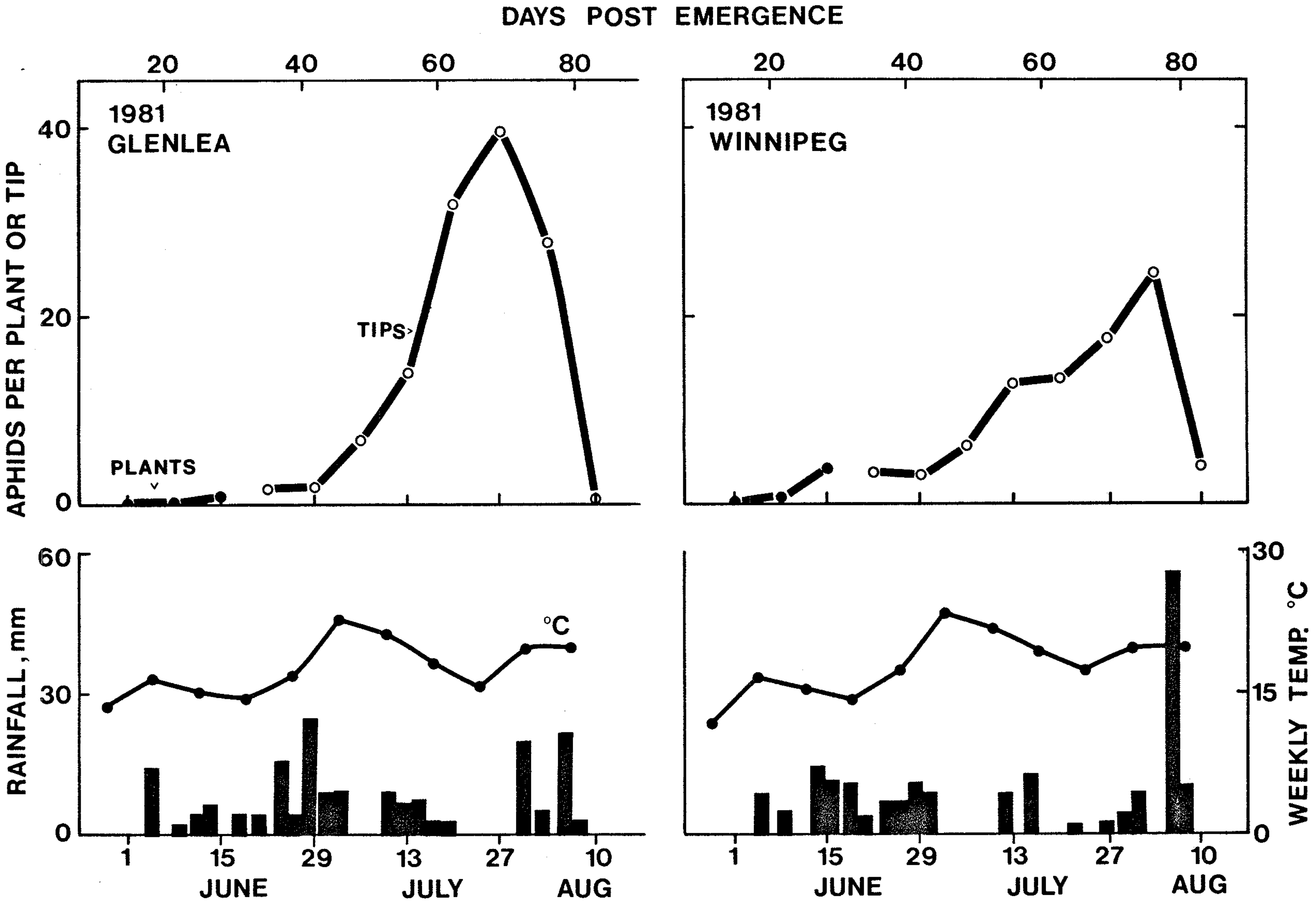
3. Results

3.1. 1981.

The seasonal temperature, rainfall and aphid populations at the two sites are shown in Fig. 2. Temperature and rainfall patterns during the study period were similar at both locations. The average monthly temperatures were 16°C in June and 20°C in July and August, within 1.5°C of the long term averages. The average temperature for the three months (growing season) were 18.4 and 18.8°C at Glenlea and Winnipeg, respectively. Cumulative degree days above 5.5°C for June through August were 1179°D at Glenlea and 1238.2°D at Winnipeg (Appendix 1). Total rainfall was 252.1 mm at Glenlea and 233.0 mm at Winnipeg, much of which fell in June and early August.

Aphids were first observed in early June at both locations but populations remained low throughout the month. Populations at Glenlea increased rapidly from 1.72 ± 0.46 (mean±s.e.) aphids per tip on 29 June to a peak of 39.6 ± 6.24 aphids per tip on 27 July. Those at Winnipeg increased from 2.92 ± 0.81 aphids per tip on 29 June to 24.62 ±3.79 aphids per tip on 3 August. The rate of population increase from 29 June to each peak was 1.35 aphids/tip/day at Glenlea and 0.57 aphids/tip/day at Winnipeg. There were large variations in numbers per tip (Appendix 2), the coefficients of variation (CV) at peak population were 111.46 and 108.85% at Glenlea and Winnipeg, respectively, indicating that aphid distribution among plant tips was not uniform. A t-test on $\sqrt{x + 0.5}$ transformed numbers per tip at peak population indicated no significant difference between locations. Aphid popula-

Fig. 2. Aphid populations on field peas, daily precipitation and mean weekly temperature at two locations in Manitoba, 1981. (●——●) Whole plant samples, (o——o) Tip samples.


DAYS POST EMERGENCE
20
40
60
80
20
40
60
80
1981
GLENLEA
1981
WINNIPEG
APHIDS PER PLANT OR TIP
40
20
0
TIPS
PLANTS
60
30
0
RAINFALL, mm
°C
30
15
0
WEEKLY TEMP. °C
1
15
29
13
27
10
JUNE
JULY
AUG
1
15
29
13
27
10
JUNE
JULY
AUG

tions decreased sharply at both locations in the first week of August to a low of 0.78 ± 0.24 and 3.90 ± 0.98 aphids per tip at Glenlea and Winnipeg, respectively.

About 78% of the aphids at Glenlea were nymphs at the time of first sampling but only 60% were nymphs at Winnipeg (Fig. 3). The proportion of nymphs increased in the second week of June to over 85% at both locations and remained at this level through the season except for a brief, slight decrease at Glenlea at the end of June.

Total numbers of adult aphids are given in Appendix 3. All adults found during the first week of June were winged (Fig. 4). As the month progressed, the proportion of winged adults decreased and by the end of June, it was 5.0% (N = 20) at Glenlea (A) and 7.1% (N = 14) at Winnipeg (B). The proportion then increased slightly to about 10% (N = 21 - 150) at both locations through July and then sharply in the first week of August to 39.5 (N = 5) and 31.3% (N = 12) at Glenlea and Winnipeg, respectively.

3.2 1982.

The 1982 season was generally cooler than in 1981 (Fig. 5, Appendix 1), with average temperatures for the growing season of 16.5 and 16.8°C at Glenlea and Winnipeg, respectively. Cumulative degree days above 5.5°C for June through August was 1013°D at Glenlea and 1054.2°D at Winnipeg. Total rainfall was 177.2 mm at Glenlea and 220.1 mm at Winnipeg, and almost one-half of it fell in July.

Fig. 3. Percentage of adult aphids (A) or nymphs (N) in the total aphid population on each sampling occasion at two locations in Manitoba, 1981-1983. Numbers across each sub-figure are for total aphids on each sampling occasion.

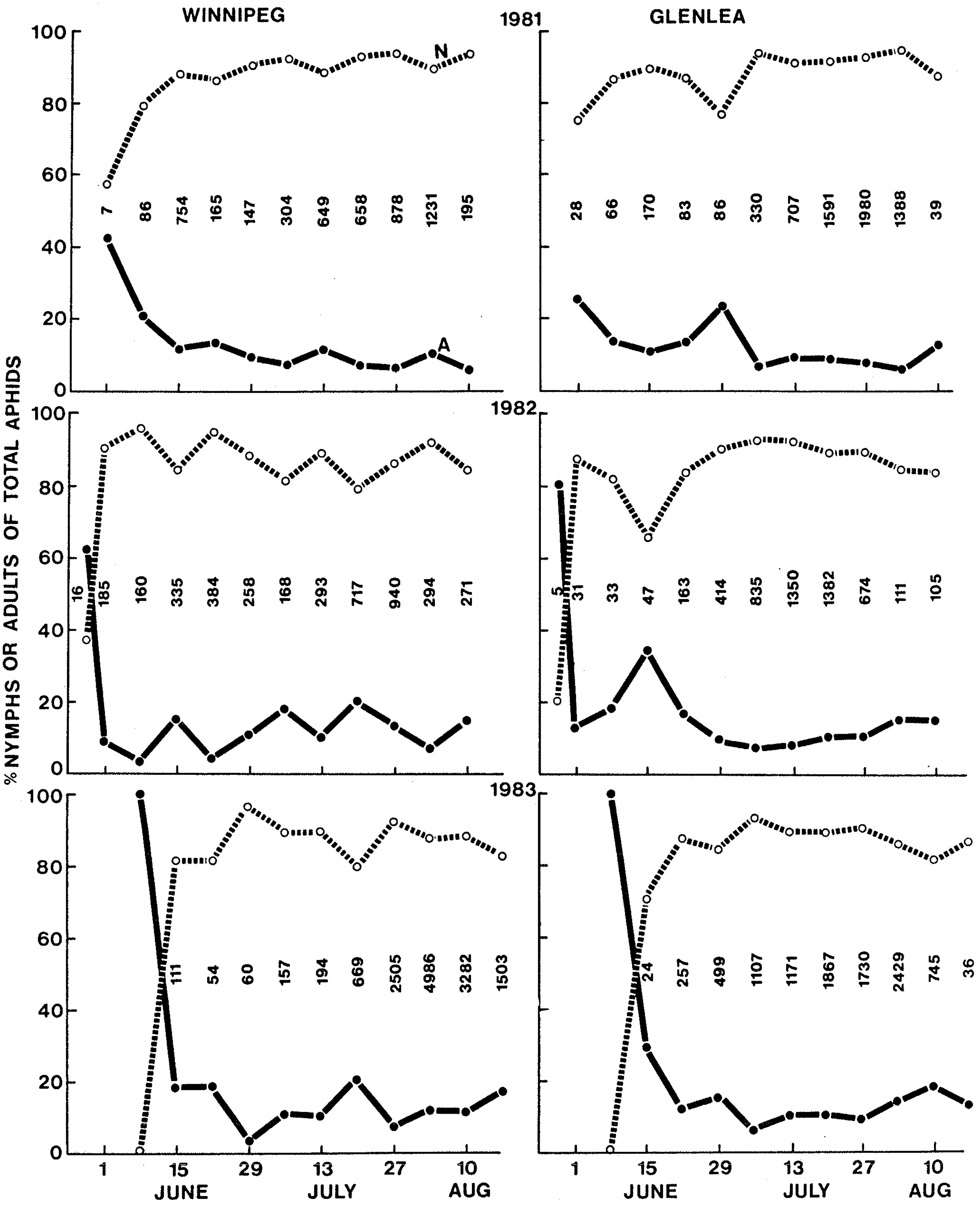

WINNIPEG
1981
GLENLEA
N
A
7 86 754 165 147 304 649 658 878 1231 195
28 66 170 83 86 330 707 1591 1980 1388 39
1982
16 185 160 335 384 258 168 293 717 940 294 271
5 31 33 47 163 414 835 1350 1382 674 111 105
1983
111 54 60 157 194 669 2505 4986 3282 1503
24 257 499 1107 1171 1867 1730 2429 745 36
% NYMPHS OR ADULTS OF TOTAL APHIDS
100
80
60
40
20
0
1
15
29
13
27
10
JUNE
JULY
AUG

Fig. 4. Percentage of winged adults among adult aphids at Glenlea (A) and Winnipeg (B), Manitoba, 1981.

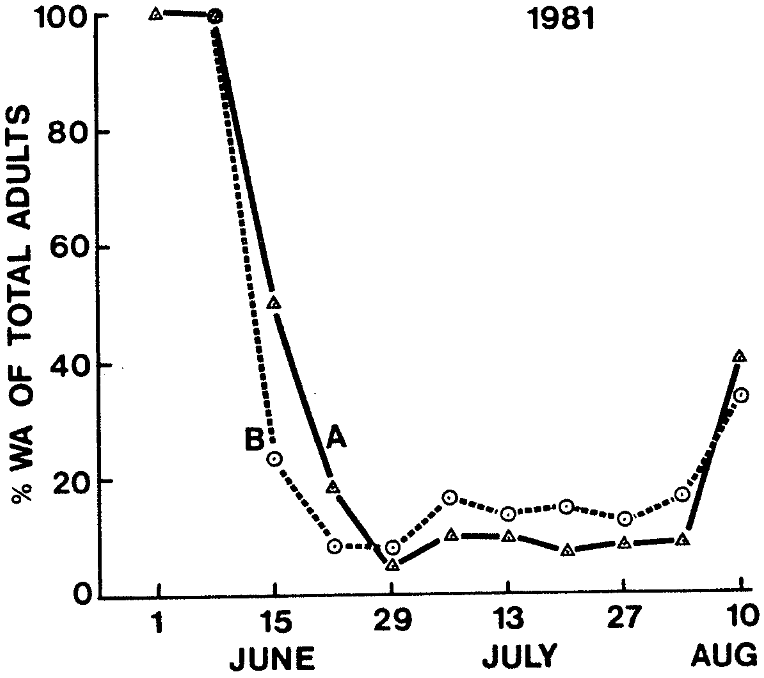
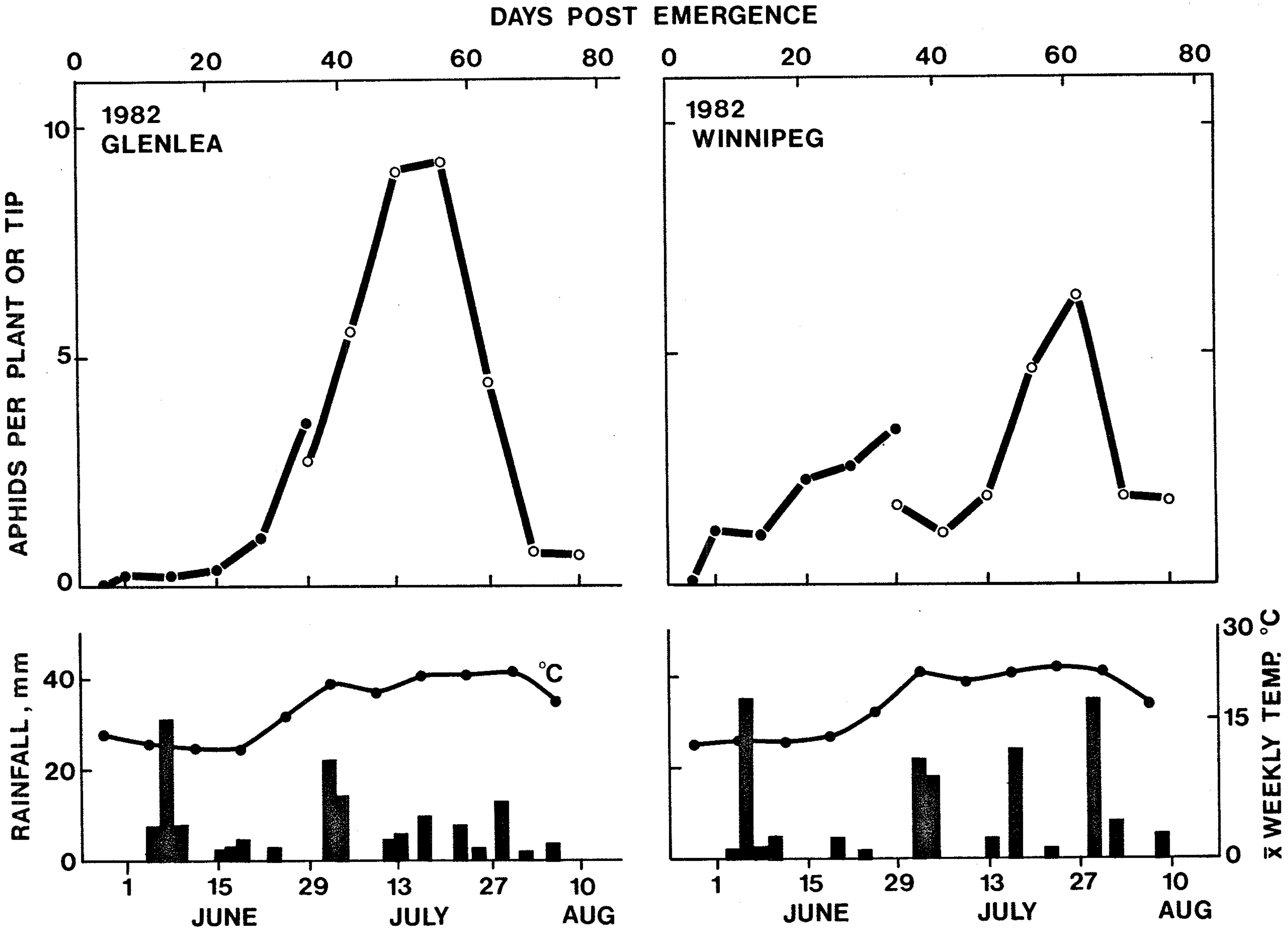

1981
% WA OF TOTAL ADULTS
100
80
60
40
20
0
A
B
1
15
29
13
27
10
JUNE
JULY
AUG

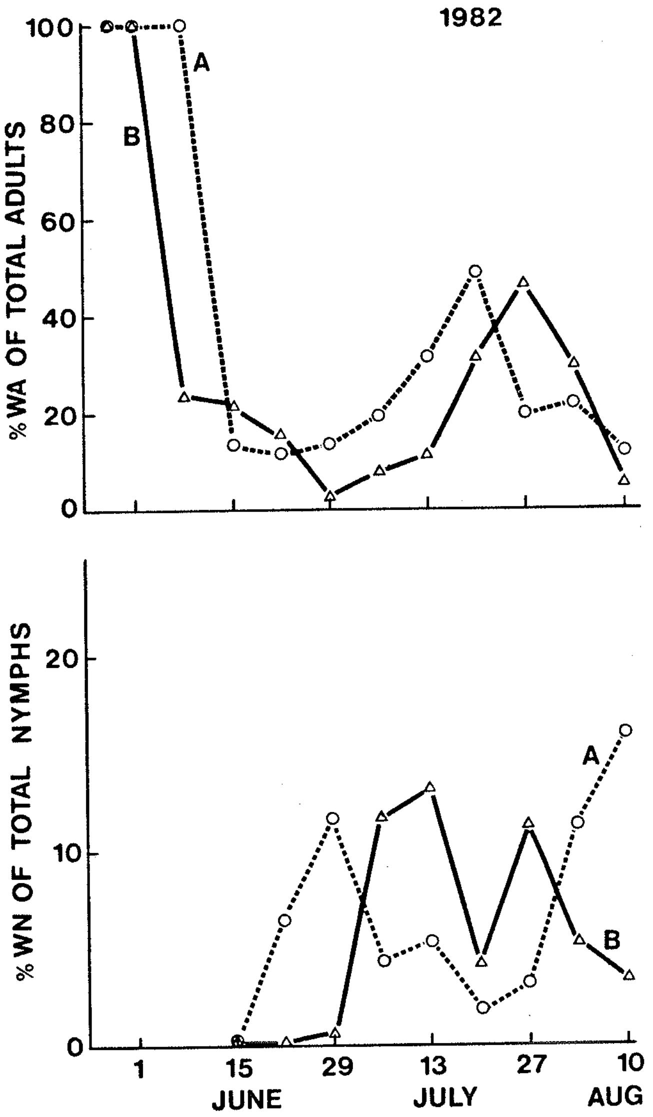
Fig. 5. Aphid populations on field peas, daily precipitation and mean weekly temperature at two locations in Manitoba, 1982. (●—●) Whole plant samples, (o—o) Tip samples.


DAYS POST EMERGENCE
0
20
40
60
80
1982
GLENLEA
1982
WINNIPEG
APHIDS PER PLANT OR TIP
10
5
0
RAINFALL, mm
40
20
0
°C
30
15
0
x̄ WEEKLY TEMP. °C
1
15
29
13
27
10
JUNE
JULY
AUG

Aphids were first collected in late May but populations remained low throughout June, with the density higher at Winnipeg than at Glenlea (Fig. 5). As in the previous year, the population began to increase in late June, but did not exceed 9.19±1.11 aphids/tip. On 29 June, aphid density at Glenlea was 3.63 ± 0.53 aphids per plant or 2.76 ± 0.52 aphids per tip and it increased to a peak of 9.19 ± 1.11 aphids per tip on 21 July. The population at Winnipeg increased from 3.35 ± 0.46 aphids per plant or 1.72 ± 0.41 aphids per tip on 29 June to 6.60 ± 0.69 aphids per tip on 27 July. The rate of population increase from 29 June to each peak was 0.29 and 0.16 aphids/tip/day at Glenlea and Winnipeg, respectively. The coefficient of variation at peak density was 147.98% at Glenlea and 129.69% at Winnipeg. Peak populations between locations were not significantly different. Sharp population declines were observed at both locations during the first week of August and aphid densities fell to 0.70 ± 0.14 aphids per tip at Glenlea and 1.81 ± 0.27 aphids per tip at Winnipeg by 10 August. About 40% of the aphids at Winnipeg and 20% at Glenlea were nymphs at the start of sampling (Fig. 3). The proportion increased to over 80% at both locations during the first week of June and fluctuated between 80 and 90% throughout the season. There was a slight decrease, however, on 15 June at Glenlea but the decrease was short lived.

As in the previous season, all adult aphids found during the first week of June were winged (Fig. 6). The proportion of adult aphids declined as the month progressed but the decline at Glenlea occurred earlier than at Winnipeg. By 29 June, 2.4% (N=29) of the adults at Glenlea and 13.7% (N=41) at Winnipeg were winged. The

Fig. 6. Percentage of winged adults (WA) and winged nymphs (WN) among total adults and nymphs at Glenlea (A) and Winnipeg (B), Manitoba, 1982.


1982
% WA OF TOTAL ADULTS
100
80
60
40
20
0
A
B
% WN OF TOTAL NYMPHS
20
10
0
A
B
1
15
29
13
27
10
JUNE
JULY
AUG

percentage increased gradually in early July and reached a peak of 46.5% (N=71) on 27 July at Glenlea and 49.0% (N=149) on 20 July at Winnipeg. There was a gradual decline to 5.8% (N=17) at Glenlea and 12.2% (N=41) at Winnipeg by 10 August.

Total numbers of nymphs are given in Appendix 3. Winged nymphs were first observed on 21 June at Winnipeg and 29 June at Glenlea (Fig. 6). The percentage of these nymphs increased to a peak of 11.8% (N=229) on 29 June at Winnipeg and 13.3% (N=1242) on 13 July at Glenlea. There was a gradual decrease to 1.9% (N=568) on 20 July at Winnipeg, then another increase to 16.1% (N=230) by 10 August. At Glenlea, the proportion decreased to 4.2% (N=2476) on 20 July, then increased again to 11.4% (N=603) on 27 July and gradually decreased to 3.4% (N=86) by 10 August.

3.3 1983.

The season was characterized by high temperatures (Fig. 7), the average temperature for the growing season being 21.5°C at Glenlea and 20.6°C at Winnipeg (Appendix 1). There were 1363°D at Glenlea and 1391.2°D at Winnipeg. Total rainfall was 155.1 mm at Glenlea and 244.2 mm at Winnipeg. More than one-half of the total rainfall at both locations fell in June but Winnipeg had more rain than Glenlea during the month (Fig. 7). In July, there were 22 to 30 mm compared with 40 to 107 mm in previous years.

The growth characteristics of pea plants are shown in Fig. 8 and Appendix 4 while a description of the growth stages is given in

Fig. 7. Aphid populations on field peas, daily precipitation and mean weekly temperature at two locations in Manitoba, 1983. (●—●) Whole plant samples, (o—o) Tip samples.

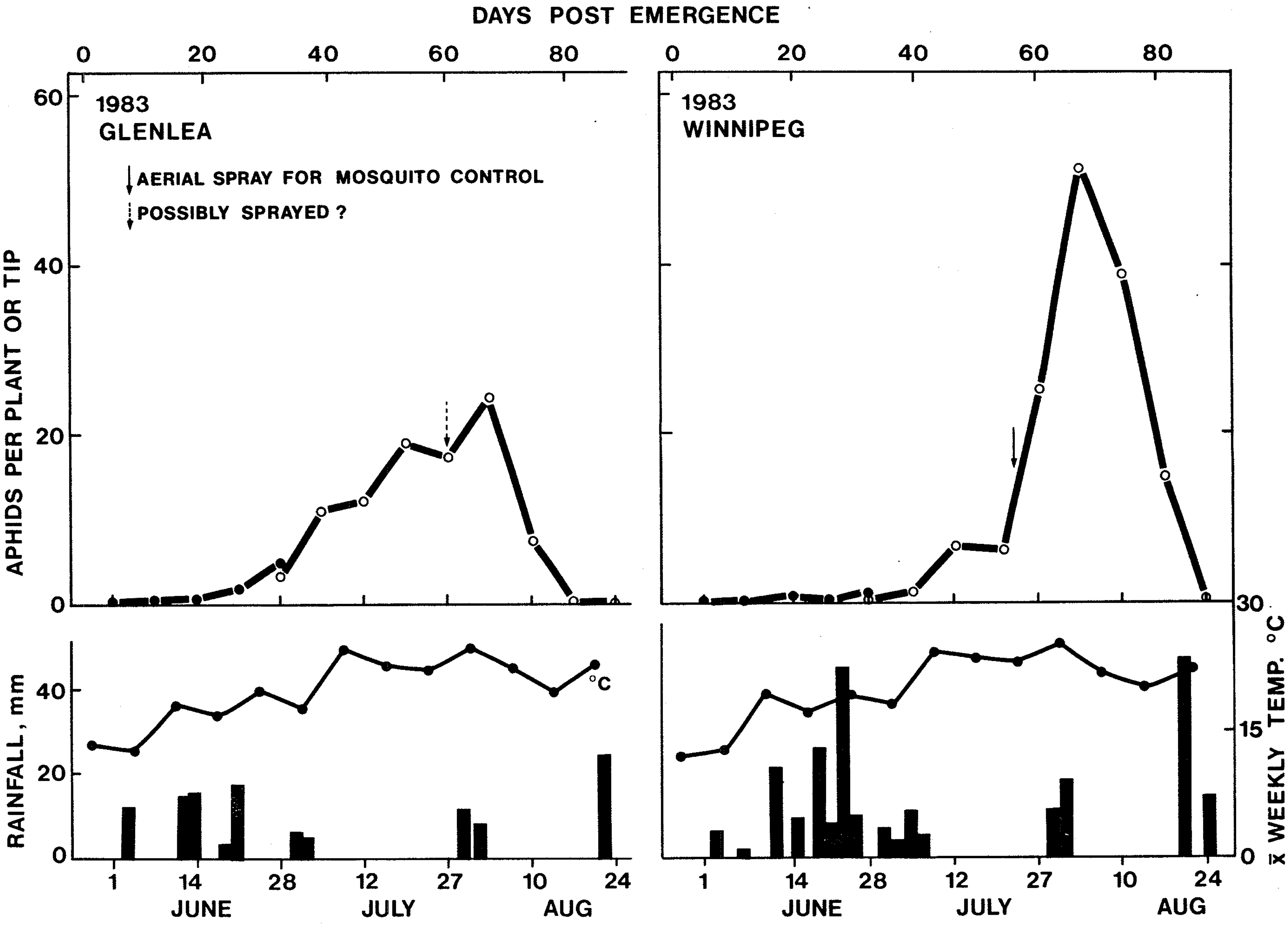

DAYS POST EMERGENCE
0
20
40
60
80
1983
GLENLEA
AERIAL SPRAY FOR MOSQUITO CONTROL
POSSIBLY SPRAYED ?
1983
WINNIPEG
APHIDS PER PLANT OR TIP
60
40
20
0
30
15
0
RAINFALL, mm
°C
x̄ WEEKLY TEMP. °C
1
14
28
12
27
10
24
JUNE
JULY
AUG

Fig. 8. Growth characteristics of the pea plant *Pisum sativum* (L.) (cv. Century) grown under field conditions at Winnipeg, Manitoba, 1983. (●———●) Average stem length, (o- - - -o) % nodes with senescent leaves, (*) Mean number of nodes per main stem. Numbers above each bar represent the days post emergence at which observations on the stage of growth were made. Where the number is not shown, days post emergence correspond to the number shown below the appropriate bar.

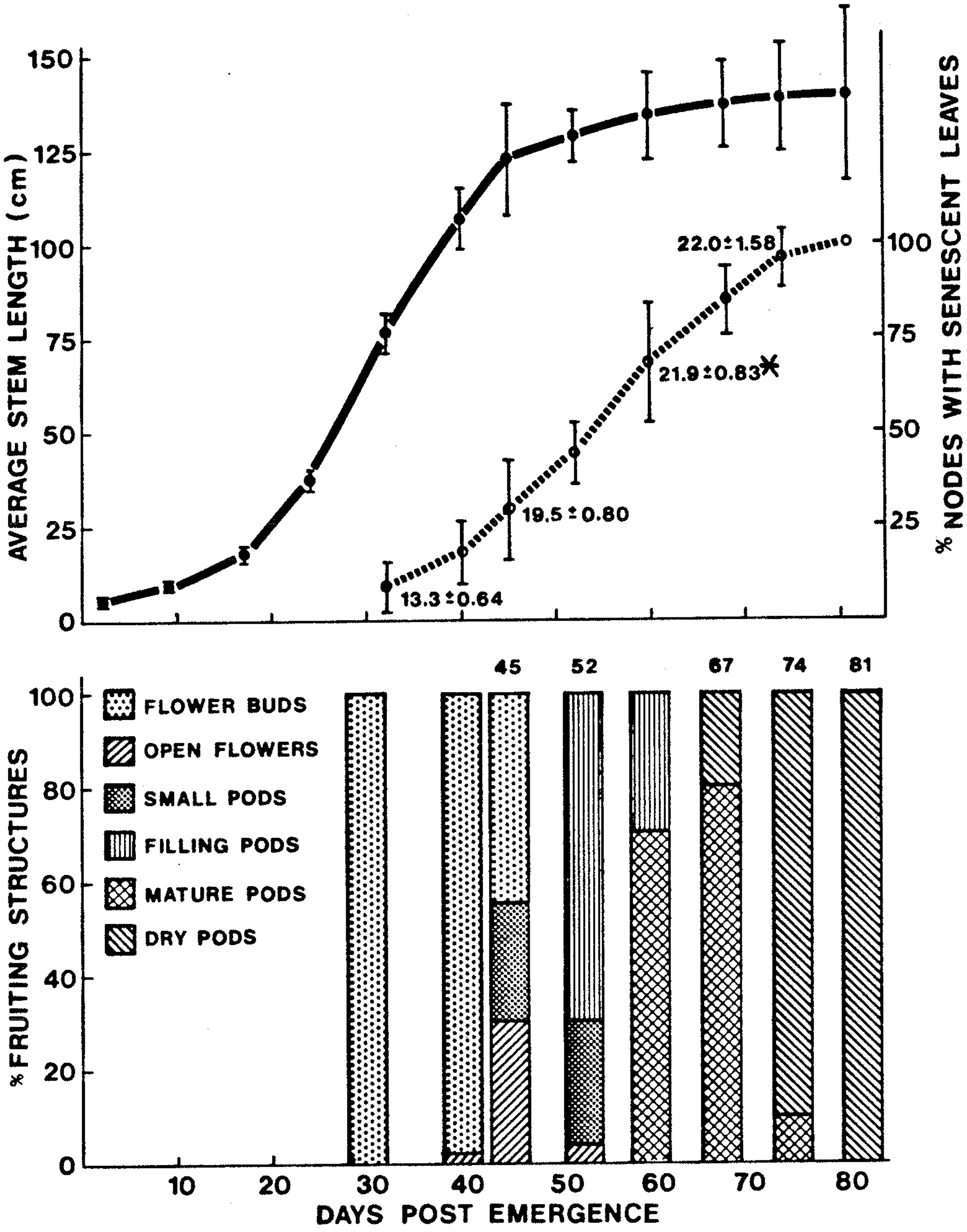

AVERAGE STEM LENGTH (cm)
150
125
100
75
50
25
0
% NODES WITH SENESCENT LEAVES
100
75
50
25
13.3 ± 0.64
19.5 ± 0.80
21.9 ± 0.83 ✱
22.0 ± 1.58
% FRUITING STRUCTURES
100
80
60
40
20
0
FLOWER BUDS
OPEN FLOWERS
SMALL PODS
FILLING PODS
MATURE PODS
DRY PODS
45
52
67
74
81
10
20
30
40
50
60
70
80
DAYS POST EMERGENCE

Table 1. The stems exhibited a sigmoid growth curve and there was considerable variation in stem length as the plants grew taller. The period of rapid stem elongation ended about 45 days after emergence in the second week of July when most of the flowers were open. The plants took approximately 80 days from emergence until all pods were dry. Plant development was divided into 8 growth stages (Table 1), some of which over-lapped.

Aphids appeared in the plots in early June during the seedling growth stage (V_1-V_5) (Table 1), but populations remained at low levels throughout the month (Fig. 7). By 28 June, aphid density was 4.86 ± 0.51 aphids per plant or 3.33 ± 0.45 aphids per tip at Glenlea and 1.11± 0.15 aphids per plant or 0.39 ± 0.12 aphids per tip at Winnipeg. Populations increased gradually at Glenlea from 28 June to 11.07 ± 1.23 aphids per tip on 6 July and 11.91 ± 1.33 aphids per tip on 12 July, and reached a peak of 24.29 ± 2.61 aphids per tip on 3 August, approximately 67 days post emergence. The plants were at the pod maturity growth stage (R_5). Those at Winnipeg increased to 1.36 ± 0.29 aphids per tip on 6 July and to 6.95 ± 1.25 aphids per tip on 12 July, and then very rapidly to a peak of 52.48 ± 5.43 aphids per tip on 3 August. The rate of population increase from 28 June to each peak was 0.59 and 1.41 aphids/tip/day at Glenlea and Winnipeg, respectively. The coefficient of variation at peak density was 107.5% at Glenlea and 100.8% at Winnipeg. Peak populations differed significantly ($P \leq 0.01$) between locations. Populations decreased rapidly during August and by 24 August, the plants were completely dry and there were no aphids. A commercial field had 1.19 ± 0.40 aphids

Table 1. Growth stage description of the pea plant <u>Pisum</u> <u>sativum</u> (L.): cv. Century at Winnipeg, Manitoba, 1983.

Stage	Stage Name	Number of Nodes	Approximate Days Post Emergence	Description
VEGETATIVE[1]				
	Emergence	0	0	Seed germination. Hypocotyl and first leaves above soil surface, but first leaves still unopened.
V_1-V_5	Seedling	1	1	Young plant. All plants have single stems with open leaves. The stage ends when at least 50% of plants have 5 nodes with fully open leaves, beginning with unifoliate node[2].
V_6-V_{13}	Lateral shoot formation & growth	6	14	Young shoots start forming at the base of at least 10% of the plants. The shoots grow into lateral stems. A stage of rapid growth and stem elongation.
REPRODUCTIVE				
R_1	Bud stage	13	30	At least 50% of plants have buds inside rolled terminal leaves. Most buds become visible when plants have 14-15 nodes or 35-40 days post emergence. Leaves at the lowermost nodes start yellowing and become senescent during this stage.

Table 1. (cont'd) Growth stage description of the pea plant <u>Pisum sativum</u> (L.); cv. Century at Winnipeg, Manitoba, 1983.

Stage	Stage Name	Number of Nodes	Approximate Days Post Emergence	Description
REPRODUCTIVE (cont'd)				
R_2	Flower	15	38	At least 10% of plants have one open flower at uppermost node. Full bloom occurs 42-45 days post emergence, by which time, 90% of plants have 1-4 open flowers on main stem.
R_3	Pod formation and enlargement	18	42	At least 10% of plants have small pods (2cm long, 0.5cm wide) and enlarged flat pods (2-6cm long 0.5-1.3cm wide) at uppermost three nodes, but no pods with apparent seeds.
R_4	Pod swelling and filling	20	49	At least 10% of plants have a pair of pods at one of the uppermost five nodes with seeds which can be felt. Pods are succulent and have sweet tasting seeds.
R_5	Pod maturity	21	57	At least 10% of plants have fully distended pods with hard seeds when squeezed. Pods turning yellow at one of the uppermost five nodes and 70% of mainstem nodes have senescent leaves.

Table 1. (cont'd) Growth stage description of the pea plant <u>Pisum sativum</u> (L.); cv. Century at Winnipeg, Manitoba, 1983.

Stage	Stage Name	Number of Nodes	Approximate Days Post Emergence	Description
REPRODUCTIVE (cont'd)				
R_6	Pod Drying	22	70	At least 50% of plants have dry pods. Leaves are dry at almost all nodes. Peas are ready for harvest 7-10 days later.

---

[1] Vegetative stages V_1-V_{13} are based on the number of nodes on the main stem. At V_6, lateral shoots start to appear at the lowest node on the main stem, and this marks the end of the seedling stage.

[2] Unifoliate node is the first node on the main stem where true leaves develop and nodes are counted beginning with this node.

per tip on 29 June, 8.45 ± 0.69 aphids per tip on 7 July and 16.00 ± 1.84 aphids per tip on July 13 when the field was sprayed with insecticide and sampling was discontinued.

The one aphid found in the first sampling was an adult but as the season progressed, the percentage of nymphs increased rapidly at both locations and fluctuated between 80 and 90% through most of the season (Fig. 3).

All adults found on 7 June were winged (Fig. 9). The percentage of winged adults decreased rapidly to 1.3% (N=78) at Glenlea and 0% (N=20) at Winnipeg by 28 June. It then increased to 25.6% (N=121) at Glenlea on 12 July and to 40.7% (N=135) at Winnipeg on 19 July when the plants were at the pod formation and enlargement growth stages (R_3). Thereafter, the proportion decreased gradually and by 17 August, about 20% (N=5) and 7.6% (N=262) of adult aphids at Glenlea and Winnipeg, respectively, were winged.

Winged nymphs were first observed on 21 June at Winnipeg and 28 June at Glenlea (Fig. 9 and 10) when the plants were in the bud stage (R_1). As the season progressed, the percentage of winged nymphs in the nymphal population increased irregularily (Fig. 9), and by 12 July, about 50% (N=457) of the third and fourth instar nymphs at Glenlea and 62% (N=88) at Winnipeg, had wing buds (Fig. 10). The percentage of winged nymphs then declined on 27 July to about 20% (N=639) at Glenlea and 30% (N=1021) at Winnipeg, but then increased in the subsequent weeks to about 38% (N=264) at Glenlea and 42% (N=1392) at Winnipeg on 10 August. By 17 August, the percentage of winged nymphs among total third and fourth instar nymphs had decreased to about 15% (N=18)

Fig. 9. Percentage of winged adults (WA) and winged nymphs (WN) among total adults and nymphs at Glenlea (A) and Winnipeg (B), Manitoba, 1983.

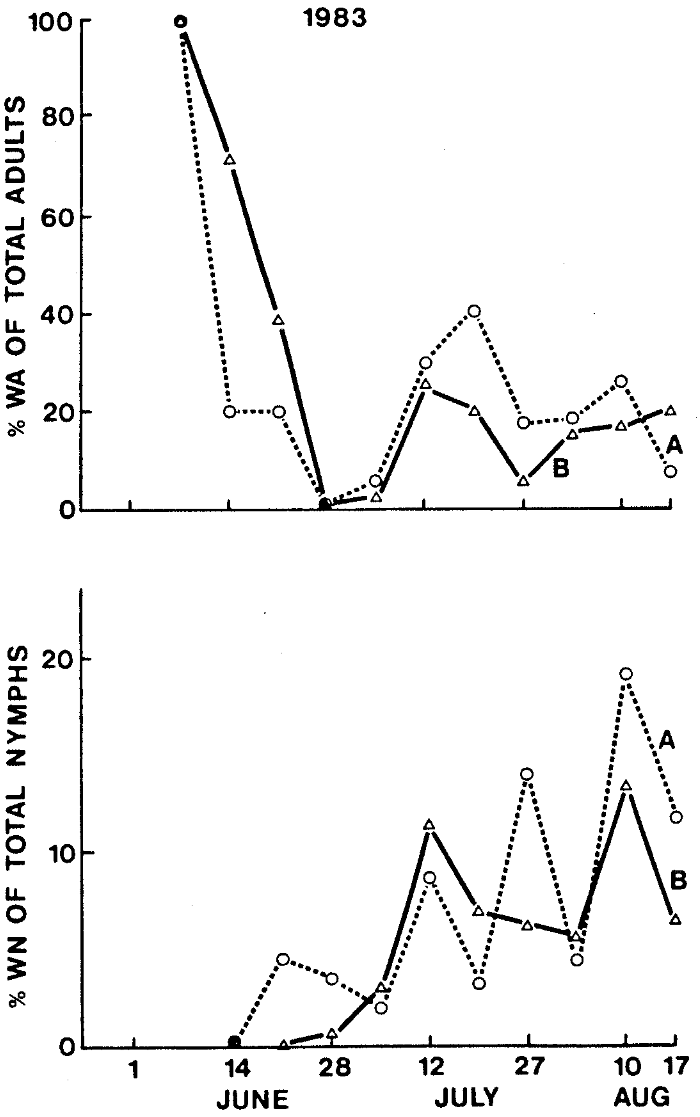
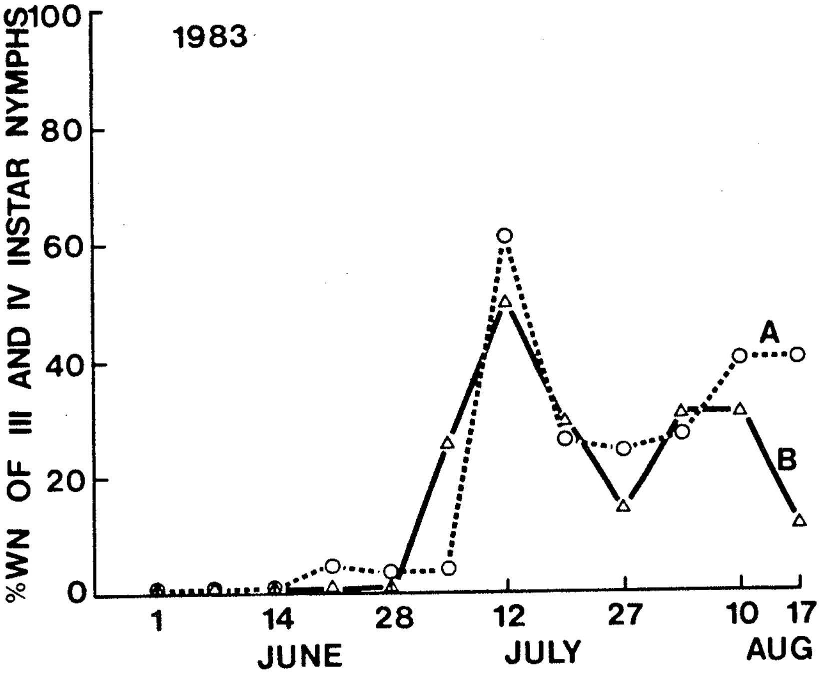

1983
% WA OF TOTAL ADULTS
100
80
60
40
20
0
A
B
% WN OF TOTAL NYMPHS
20
10
0
A
B
1
14
28
12
27
10
17
JUNE
JULY
AUG

Fig. 10. Percentage of winged nymphs (WN) to total III and IV instar nymphs at Glenlea (A) and Winnipeg (B), Manitoba, 1983.


1983
%WN OF III AND IV INSTAR NYMPHS
100
80
60
40
20
0
1
14
28
12
27
10
17
JUNE
JULY
AUG
A
B

at Glenlea, while that at Winnipeg had increased slightly to about 43% (N=358).

4. Discussion

Several studies on the dynamics of populations of pea aphids have reported two peaks, one in late spring or early summer and another one in late summer or early fall (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971). In the present study, only one peak was observed in mid-summer at both locations each year at the pod maturity (R_5). The long winters in Manitoba delay crop seeding and the beginning of aphid infestations, thus delaying time to peak populations. The crop ripens soon after the first peak is reached and so there is insufficient time for a second peak to develop. Apart from the population growth pattern at Glenlea in 1983, both locations had similar patterns of population growth. The rate of population increase varied from 0.16 to 1.41 aphids/tip/day, a somewhat narrower range than reported by Cooke (1963) for alfalfa and pea fields in Eastern Washington and Oregon. Peak populations at a location differed from year to year ($P \leq 0.01$) but there were no significant differences in peak densities between locations, except in 1983 ($P \leq 0.01$) and the difference in that year may have been due to different exposures to insecticide applied for mosquito control.

Rainfall and cold weather may reduce aphid populations (Dunn and Wright 1955; Cooke 1963). The lower and upper temperature limits for development of the pea aphid have been reported as 2.7-5.5° and 25 -

30°C, respectively (Campbell 1974; Campbell and Mackauer 1975, 1977; Hutchison and Hogg 1984). During the present study, weather was different from year to year. Cumulative degree days above 5.5°C were highest in 1983 and lowest in 1982 (Appendix 1). In 1982, much of the rain fell in July instead of June as in 1981 and 1983. The results reported here indicate that densities of pea aphids start increasing in late June or early July as the summer starts warming up. During June, temperatures are generally low and rainfall is high, and such weather probably prevents rapid population increase. The 1982 season was cool and wet during the period when aphid densities started to increase and remained so throughout July. This might have contributed to the low rates of population increase and consequently, the low densities that year.

Most of the aphids found during the study were nymphs. Similar results were reported by Cooke (1963). The occurrence of nymphs on the first day of sampling in 1981 and 1982 indicates that the winged adults had colonized the plants earlier. Although it was expected that there would be more nymphs than adults due to the short teneral period and high reproductive rate in pea aphids (Cartier 1960; Kilian and Nielsen 1971; Siddiqui et al. 1973), the proportion of the adults might have been underestimated due to the tendency of adult aphids to drop off the plants, an error which was difficult to eliminate completely.

The influence of natural enemies on aphid populations has been reported (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971; Campbell 1974; Stary 1974; Frazer et al. 1981). Their influence was not considered in the present study but many Coccinellid beetles and larvae of Syrphid flies were seen in the plots during sampling. There were also mummified aphids on leaves of plants, especially in July. The aphid mummies were kept in incubators and parasites which emerged were identified as *Aphidius ervi* Haliday and *Praon pequodorum* Viereck (Identifications by F. Matheson, Agriculture Canada Research Station, Winnipeg). The rapid increase in aphid populations after an aerial spray with malathion for mosquito control in Winnipeg in 1983 suggests that predators and/or parasites may have been important in suppressing aphid populations. Insecticide applications are known to reduce parasites and predators, thus resulting in pest resurgence (Smith and Hagen 1959, Van den Bosch and Stern 1962). It is possible that the spraying affected the natural enemies more than the aphids, thus resulting in an increase of the aphid population. A slight increase in aphid density was also observed at Glenlea which was at the edge of a sprayed area.

Immigration and emigration of winged aphids have been suggested to affect aphid populations (Cooke 1963; Campbell 1974). The immigrant winged aphids colonize the plants and augment the reproductive rate of local populations, while the emigrants fly away. All adults found early in the season were winged. This is expected since both host plant selection and colonization by aphids early in the season is accomplished by the winged forms emigrating from the winter and spring hosts (Kennedy *et al*. 1961). Increases in aphid densities and crop maturity (Sutherland 1969a, b) may have stimulated production of winged aphids and these, together with other winged pea aphids immigrating from other fields could have led to the increase in winged adults later in the season. Campbell (1974) observed similar trends in proportions of winged adults with increases in aphid densities and alfalfa maturity. The increase in winged aphids towards the end of July may have led to high rates of emigration and thus population decrease.

No winged nymphs were produced in the first two weeks of June, probably because most of the nymphs were offspring of alate immigrants which produce few or no winged offspring (MacKay 1977). When the winged nymphs were first observed, the plants appeared healthy and were growing rapidly. However, the pair of leaves on the lowest nodes of some plants had started yellowing and senescing, perhaps indicating that plant quality was starting to deteriorate despite the healthy green appearance of the plants. The aphid densities were still very low but many were found clustered on plant tips, perhaps causing local crowding. Host plant condition and crowding are important in the production of winged pea aphids (Sutherland 1967, 1969a, b). From the present study, it was not possible to determine which of these factors played a significant role in the production of winged nymphs early in the season.

Although the factors discussed thus far undoubtedly played a role in influencing the rates of population increase, crop development probably influenced the timing of population decline. Throughout June and July, the plants were growing rapidly and provided abundant new foliage. This was also the period when aphid populations were increasing. During late July and early August, the plants started to turn yellow and senesce, and aphid populations decreased rapidly (Fig. 2, 5 and 7). As the plants dried, most aphids disappeared but some could still be found clustering on the tips of the remaining green plants. Population declines with increase in crop maturity have been reported previously (Dunn and Wright 1955; Cooke 1963; Campbell 1974).

This study shows that the pea aphid invades pea fields very early in the season when the crop is at the seedling stage (V_1-V_5). However, populations remain low throughout June and start increasing in early July when the plants are at the flowering (R_2) and pod formation (R_3) growth stages. Peak populations are reached towards the end of July or at the beginning of August when the plants are at the pod maturity growth stage (R_5), and populations decrease rapidly to low levels as the plants mature and dry. It appears that aphid control programs should be aimed at preventing the rapid increase of aphid populations in early July, but in years with wet and cool summers, rapid population increases do not occur and control programs are therefore unnecessary. During the short period when the farmer's field was sampled, the populations were higher than those in the experimental plots and it appears that those in the field would have reached high levels in the absence of the insecticide spray. Differences in density between the population at Glenlea and Winnipeg were not as great as differences among years. The cause of the seasonal patterns and annual variations are yet to be fully understood.

SECTION II

Effect of the Pea Aphid, *Acyrthosiphon pisum* (Harris), (Homoptera: Aphididae) Infestations on Pea Plants at Different Growth Stages.

ABSTRACT

Pea plants *Pisum sativum* (L.) (cv. Century) in field cages were infested at different growth stages with different densities of the pea aphid in 1981 and 1982. In 1981, all yield parameters except protein content of the seeds, were affected by density of aphids and growth stage of the plants at time of infestation. In 1982, aphid feeding during the vegetative stage alone did not affect yields, but feeding through flowering, pod filling and pod maturity stages resulted in significantly lower yields than noninfested plants. Yield reductions resulted from pod shedding, reduced number of seeds per pod and reduced seed weight.

1. Introduction

Plants differ in susceptibility to insect damage according to growth stage at time of infestation. At any growth stage, the amount of damage depends on the number of insects feeding on the plant. Knowledge of the critical stage of plant growth and infestation level at which damage occurs is important for the rational use of pesticides. Several authors have identified critical stages and infestation levels at which injury to the plant caused severe yield reductions (Wells and McDonald 1961; Apablaza and Robinson 1967; Ogulana and Pedigo 1974; Schoonhoven *et al*. 1978; Ba-Angood and Stewart 1980b; Pettit and Smilowitz 1982). However, other than the reports from laboratory studies using young pea plants (Barlow *et al*. 1977; Barlow and Messmer 1982), few data are available about the relationship between stage of crop growth or level of infestation and the kinds of damage caused by the pea aphid, *Acyrthosiphon pisum* (Harris), on field peas, *Pisum sativum* (L.).

The purpose of this study was to determine the effect of feeding by different densities of the pea aphid at different stages of plant growth on the yield of field peas.

2. Materials and Methods.

The experiments were conducted at the Agriculture Canada Research Station, Winnipeg, during the summers of 1981 and 1982. Pea plants (cv. Century) were hand seeded on 13 May 1981 and 16 May 1982, under

$1m^3$ field cages made of Saran screen. Each cage was seeded with three rows, 30 cm apart and after germination the plants were thinned to 20 and 10 plants per cage in 1981 and 1982, respectively. Plant density per cage was reduced in 1982 to facilitate observation of the plants.

Pea aphids were reared on young pea plants (cv. Century) in the greenhouse using a method similar to that described by Nault (1969). Rearing conditions were 20-25°C and 16-h photoperiod. The clone was collected from an alfalfa field in Manitoba and had been reared on pea plants in the greenhouse for almost a year. A comparison of the clone with other clones collected from pea fields during the study period indicated that it had similar biological characteristics to these clones (Table 2).

In 1981, 0, 5, 10, 15 and 20 adult apterous aphids were introduced per cage at 14, 35, and 50 days post emergence (A, B and C, respectively) (Fig. 11). A density of 10 aphids per cage was approximately equivalent to the density per plant in the field 14 days post emergence, and the days at which infestations were established coincided with the start of the lateral shoot formation (V6), flowering (R2) and pod filling (R4) growth stages (Table 1, Section 1). A factorial experiment with a completely randomized design was used, with each treatment replicated twice. After each infestation, the aphids were left to feed on the plants until harvest.

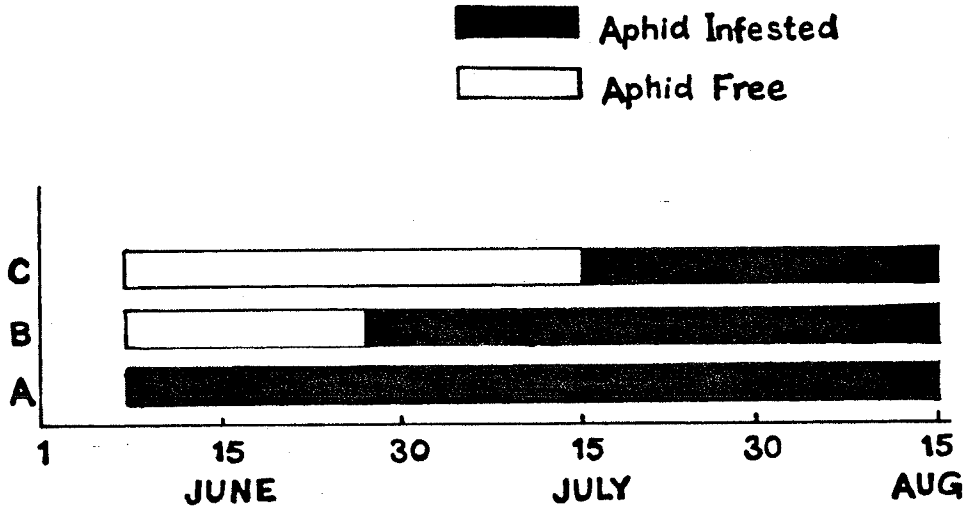
At maturity, all pods in each cage were hand harvested and categorized as empty or filled. The number of pods per plant, seeds per pod, seed yield, 1000 seed weight and dry weight of stems and leaves

Table 2. Mean developmental time, reproductive output and survival time from the onset of reproduction for eight aphid clones.

Source	Days to adult $\bar{X}$ ± S.D.	$\bar{X}$±S.D. offspring/ 1st 4 days	$\bar{X}$±S.D. offspring/ 1st 7 days	$\bar{X}$±S.D. survival (days) post teneral
Glenlea	7.40 ± 0.56	34.40 ± 3.77	57.40 ± 6.18	12.80 ± 2.57
Aubigny A	8.25 ± 0.64	31.00 ± 8.94[1]	48.16 ± 18.49[1]	10.83 ± 3.82[1]
Aubigny B	7.50 ± 0.51	33.70 ± 4.59	55.70 ± 13.81	11.70 ± 2.98
Winnipeg	7.75 ± 0.55	28.00 ± 4.89[1]	47.50 ± 5.39[1]	12.00 ± 2.19[1]
Starbuck A	7.95 ± 0.39	36.40 ± 6.20	57.80 ± 13.22	10.30 ± 2.86
Starbuck B	8.10 ± 0.72	32.00 ± 4.47	52.00 ± 11.25	11.90 ± 3.17
Kane	8.00 ± 0.56	28.70 ± 4.80	46.60 ± 12.11	12.40 ± 2.91
Greenhouse	8.10 ± 0.45	31.90 ± 4.75	52.70 ± 11.84	10.70 ± 3.09
Mean	7.88 ± 0.28	32.01 ± 4.56	52.23 ± 8.54	11.46 ± 2.05
N	20	10	10	10

[1] N = 6

Fig. 11. Infestation plans (A, B & C) in field cages, 1981.


Aphid Infested
Aphid Free
C
B
A
1
15
30
15
30
15
JUNE
JULY
AUG

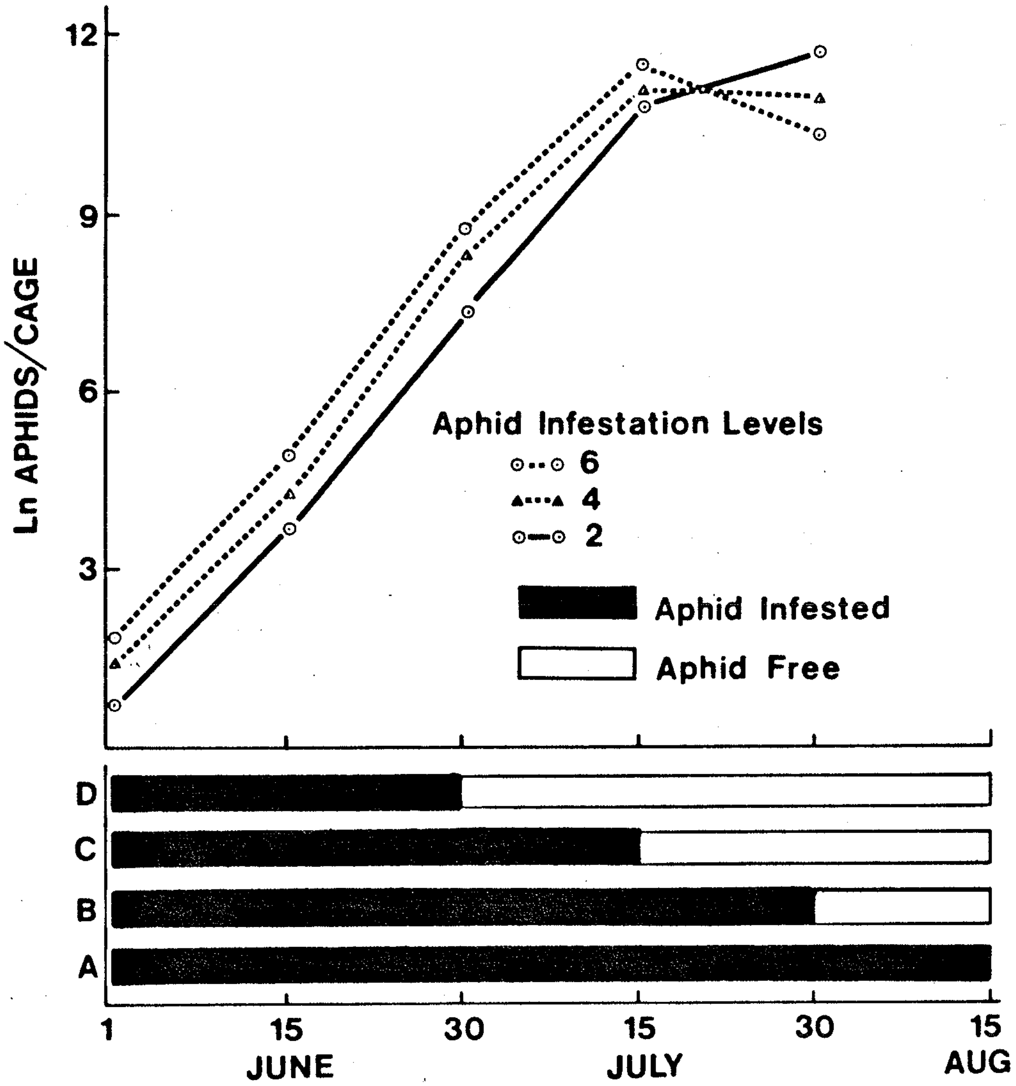
were determined. Protein content of the seeds was determined (M. Hodgins, Agriculture Canada Research Station, Morden) by the Kjeldhal method (AOAC 1975).

In 1982, the plants in all cages except the controls were infested 7 days after emergence with 2, 4 and 6 aphids per cage. A density of 4 aphids per cage was approximately equivalent to the density per plant in the field at that time. The aphids at each infestation level were allowed to feed for variable periods A, B, C and D (Fig. 12). Period A covered all stages from infestation to harvest (V_3-R_6), B covered the vegetative, flowering and pod filling stages (V_3-R_4), C covered the vegetative and flowering stages (V_3-R_2) while D covered only the vegetative stage (V_3-R_1). For each period of infestation there was a control consisting of a cage containing aphid free plants. The experimental design and replicates were similar to those used in 1981.

Fifteen days after infestation, aphids in all cages were counted in situ. Subsequently, at the end of each period (A, B, C or D), the aphids in that treatment were collected in enamelled metal trays and were stored in 65% alcohol. The plants were then sprayed with 0.75 l a.i./ha of malathion to kill any remaining aphids, and were left to mature.

Estimates of the number of aphids collected from each cage were made as follows. Ten, 2 ml samples of fresh aphids were taken from the aphids which had been collected at each termination day and were counted. The samples were then dried at 70°C for 48 hours and cooled overnight. The dry weight of each sample was determined and the

Fig. 12. Feeding durations (A, B, C & D) and estimated final aphid numbers from three initial infestation levels in a cage experiment at Winnipeg, Manitoba, 1982.



12
9
6
3
Ln APHIDS/CAGE
Aphid Infestation Levels
6
4
2
Aphid Infested
Aphid Free
D
C
B
A
1
15
30
15
30
15
JUNE
JULY
AUG

average weight of an aphid was calculated. The remaining aphids from each cage were dried similarly and their dry weights determined. Aphid density per cage was then calculated by dividing the total dry weight of aphids per cage by the estimated average weight per aphid.

At the flowering stage, about 60% of the flowers in each cage were tagged and the percentage of flowers shed was determined. At maturity, the plants were hand harvested and data were recorded as in the previous year except that the 1000 seed weight and protein content of the seeds were not recorded because there were insufficient seeds from some cages. In addition, 15 infested and noninfested plants were uprooted and the fresh weights of the root nodules were taken to determine the effect of aphid feeding on nitrogen fixation by the plants (Miller *et al*. 1982).

Data were analyzed by analysis of variance using the Agriculture Canada (Agrinet) computer programs. The number of pods per plant and seeds per pod were $\sqrt{x + 0.5}$ transformed while the percentage of empty pods, flowers shed and protein were Arcsine transformed before analysis. Means were compared by Duncan's new multiple range test (Steel and Torrie 1980). Correlation coefficients between yield and yield components were also calculated. A significance level of $P \leq 0.05$ was adopted unless otherwise stated.

3. Results

3.1. 1981.

Aphid densities inside the cages were not estimated but were higher than densities usually found in commercial fields, especially in cages where they were introduced at the vegetative stage (V_6). Plants infested at the growth stage when lateral shoots formed (V_6) always produced significantly fewer pods and a greater percentage of empty pods than noninfested plants or those infested at later growth stages, regardless of the infestation level (Table 3). There were no significant differences in numbers of pods per plant between plants infested at the flowering (R_2) and pod filling (R_4) growth stages, and noninfested plants. Plants infested at the flowering growth stage had a significantly greater percentage of empty pods than noninfested plants or those infested during the pod filling stage when the initial infestation was 15 or 20 aphids per cage (Table 4).

Seed yield and 1000 seed weight for plants infested at the stage when lateral shoots formed were significantly lower than for noninfested plants and those infested at the flowering and pod filling growth stages (Tables 5 & 6). At all growth stages, seed yield and 1000 seed weight dropped as the level of infestation increased but the differences were not significant. There were no consistent or significant differences in protein content of seeds from infested and noninfested plants (Table 7).

The yields of dry matter from plants infested at the stage when lateral shoots formed were significantly different from those of noninfested plants but differences between infestation levels were not significant (Table 8). Infestation of plants at the flowering or pod filling stages did not cause significant reductions in dry matter. There was a small increase in dry matter when plants at the pod filling stage were infested with 15 or 20 aphids.

Table 3. Pods per plant for peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation level (aphids/cage)[1]					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	20.05a[2]	5.33c	6.02c	2.55c	3.62c	0.42
Flower	17.89ab	22.43a	19.76a	20.62a	20.84a	0.20
Pod filling	19.20ab	19.80a	21.22a	22.63a	25.76a	0.17

[1] Analysis of variance for pods per plant at levels of infestation was performed on $\sqrt{x + 0.5}$ data, and the S.E. for means are from transformed data.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 4. Percent empty pods[1] for peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation (aphids/cage)[2]					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	0.37a[3]	30.21d	33.59e	32.50e	20.79c	0.83
Flower	0.43a	0.59a	1.36a	3.03b	4.11b	0.24
Pod filling	0.12a	0.93a	3.06b	0.97a	1.20a	0.30

[1] Percent empty pods of total pods for plants in each cage.

[2] Analysis of variance for empty pods at levels of infestation was performed on Arcsine transformed data, and the S.E. for means are from transformed data.

[3] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 5. Seed yield (g)[1] for peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation level (aphids/cage)					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	415.00ab[2]	42.50c	40.00c	22.50c	26.20c	19.22
Flower	394.50ab	387.50ab	371.00ab	323.70b	324.70b	24.98
Pod filling	404.20ab	402.00ab	375.00ab	438.20a	391.20ab	7.49

[1] Seed yield of plants in each cage.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 6. Weight of 1000 seeds (g)[1] for peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation level (aphids/cage)					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	248.75a[2]	161.10d	151.50d	186.80c	152.05d	4.05
Flower	254.05a	238.60a	228.65ab	233.15a	213.75b	5.21
Pod filling	267.00a	252.65a	236.75a	249.30a	246.70a	7.77

[1] For seeds from each cage.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 7. Percent protein[1] for seeds of peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation level (aphids/cage)[2]					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	22.27a[3]	20.52a	22.59a	22.77a	24.34a	1.94
Flowers	21.04a	21.15a	20.19a	20.80a	20.55a	0.36
Pod-filling	22.36a	21.08a	22.36a	21.30a	20.70a	0.61

[1] Seed quality based on % crude protein (N x 6.25), Kjeldahl method.

[2] Analysis of variance for % protein at levels of infestation was performed on Arcsine transformed data, and the S.E. for means are from transformed data.

[3] Means followed by the same letter are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 8. Dry matter yield (g/plant) for peas (cv. Century) infested with 5 densities of pea aphids at 3 stages of plant growth at Winnipeg, Manitoba, 1981.

	Initial infestation level (aphids/cage)					
Growth Stage	0	5	10	15	20	S.E.
Vegetative	21.63ab[1]	13.37d	11.36d	13.29d	12.44d	1.33
Flowers	16.27bcd	18.30bcd	15.84cd	14.41cd	16.81bcd	0.86
Pod-filling	18.45bcd	15.62cd	17.50bcd	19.50bc	24.90a	1.14

[1] Means followed by the same letter are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

3.2 1982.

Aphid densities inside the cages increased to high levels in proportion to initial infestation levels (Fig. 12). By July 15, aphid densities in cages infested with 4 and 6 aphids and left unsprayed had reached densities which caused the plants to yellow prematurely. Aphid densities in these cages declined sharply in subsequent weeks as plants died. The plants in cages infested with 2 aphids and left unsprayed were still green on July 15 and aphid densities continued to increase. However, two weeks later, aphid numbers were so high that the plants dried, and all the aphids died.

Plants infested up to flowering (R_2), pod filling (R_4) and pod drying (R_6) shed a significantly greater percentage of flowers and consequently formed fewer pods per plant than noninfested plants or those where aphid feeding occurred only during the vegetative stage (V_3-R_1) (Tables 9 & 10). The magnitude of flower shedding and pod reduction was dependent upon the duration of feeding and the initial infestation. There were no significant differences in flowers shed or pods per plant between noninfested plants and those infested only during the vegetative stage.

Aphid feeding through all growth stages or into the pod filling stage resulted in significantly fewer seeds per pod and lower seed yield than for noninfested plants or those where feeding occurred in the vegetative or the vegetative and flowering growth stages, regardless of infestation level (Tables 11 & 12). The reductions in number of seeds per pod and seed yield in unsprayed plants and those infested

Table 9. Percent flowers shed by peas (cv. Century) infested with 4 densities of pea aphids for 4 periods at Winnipeg, Manitoba, 1982.

Stage Sprayed	Initial infestation level (aphids/cage)[1]				
	0	2	4	6	S.E.
Vegetative	2.17a[2]	0.00a	2.85a	0.87a	5.05
Flower	3.12a	5.12a	48.86bc	72.37d	9.49
Pod filling	2.17a	29.85b	74.00d	100.00e	6.51
Unsprayed	3.33a	54.31cd	69.92cd	100.00e	9.15

[1] Analysis of variance for % flowers shed at levels of infestation was performed on Arcsine transformed data, and the S.E. for means are from transformed data.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 10. Pods per plant for peas (cv. Century) infested with 4 densities of pea aphids for 4 periods at Winnipeg, Manitoba, 1982.

Stage Sprayed	Initial infestation level (aphids/cage)[1] 0	2	4	6	S.E.
Vegetative	23.77a[2]	24.67a	25.03a	25.25a	0.18
Flower	25.05a	17.55bc	16.62c	8.47d	0.39
Pod filling	24.20a	2.40e	0.85e	0.15e	0.07
Unsprayed	22.62ab	1.17e	0.72e	0.00e	0.26

[1] Analysis of variance for pods per plant at levels of infestation was performed on $\sqrt{x + 0.5}$ transformed data, and the S.E. for means are from transformed data.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 11. Seeds per pod for peas (cv. Century) infested with 4 densities of pea aphids for 4 periods at Winnipeg, Manitoba, 1982.

	Initial infestation level (aphids/cage)[1]				
Spray	0	2	4	6	S.E.
Vegetative	4.37a[2]	4.21a	4.04a	4.25a	0.02
Flower	4.15a	3.56a	3.63a	4.17a	0.70
Pod filling	4.00a	1.89b	1.06bc	0.75c	0.04
Unsprayed	4.00a	0.88bc	0.63c	0.00c	0.17

[1] Analysis of variance for seeds per pod at levels of infestation was performed on $\sqrt{x + 0.5}$ transformed data, and the S.E. for means are from transformed data.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 12. Seed yield (g)[1] for peas (cv. Century) infested with 4 densities of pea aphids for 4 periods at Winnipeg, Manitoba, 1982.

	Initial infestation level (aphids/cage)				
Spray	0	2	4	6	S.E.
Vegetative	499.00a[2]	520.50a	480.50a	531.50a	49.09
Flower	484.00a	246.50b	249.00b	154.50b	58.63
Pod filling	498.50a	12.50c	1.67c	0.33c	16.45
Unsprayed	465.00a	6.00c	4.93c	0.00c	5.87

[1] Seed yield of plants in each cage.

[2] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

through the pod filling stage increased with infestation level, but the differences were not usually significant. Plants which were infested up to the flowering stage or longer always had fewer seeds per pod and lower seed yield than noninfested plants or those fed on only during the vegetative stage but only the difference in seed yield was significant. Different infestation levels did not result in significant differences in seed yield although there was a trend for reduced yield at higher infestation levels. Aphid feeding during the vegetative stage alone did not reduce the number of seeds per pod or seed yield.

All plants where aphid feeding continued until after the flowering and pod filling stages, or up to harvest produced less dry matter than the noninfested or those which were infested only during the vegetative stage, regardless of infestation level (Table 13). However, significant differences in dry matter were only observed where aphid feeding continued until after pod filling or to harvest. The yield of dry matter tended to decrease with infestation level, but the differences were not usually significant.

The fresh weight of nodules from infested plants was 0.09 ± 0.13 g while that of noninfested plants was 0.49 ± 0.38 g, the difference being significant (t-test, $P \leq 0.01$).

Correlations between yield and yield components were significant and the components ranked in descending order of their correlation coefficients were: pods per plant, 1000 seed weight, seeds per pod and dry matter per plant (Table 14).

Table 13. Dry matter yield (g/plant) for peas (cv. Century) infested with 4 densities of pea aphids for 4 periods at Winnipeg, Manitoba, 1982.

	Initial infestation level (aphids/cage)				
Stage Sprayed	0	2	4	6	S.E.
Vegetative	18.22bcd[1]	17.82bcd	19.22bc	18.65bcd	1.51
Flowers	25.65a	17.67bcd	16.25bcd	15.72bcde	3.52
Pod-filling	18.45bcd	12.40de	10.30e	9.82e	1.02
Unsprayed	21.75ab	11.82e	13.92de	9.90e	1.03

[1] Means followed by the same letter(s) are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

Table 14. Correlation coefficients ($P \leq 0.001$) between yield and yield components (cage expts.) - 1981-1982.

Yield	1981			1982		
	1000 seed wt.	Pods/ plant	Dry matter/ plant	Pods/ plant	Seeds/ pod	Dry matter/ plant
Total yield/ cage	0.931	0.9444	0.693	0.981	0.862	0.800
Seed yield/ plant	0.918	0.959	0.736	0.974	0.826	0.752
Dry matter/ plant	0.667	0.725		0.824	0.755	

4. Discussion

Feeding by pea aphids is known to remove nutrients, auxins and photosynthates from plants (Maxwell and Painter 1962a & b; Harper and Lilly 1966; Harper and Kaldy 1978; Barlow et al. 1977; Barlow and Messmer 1982). The nutrients, auxins and photosynthates are necessary for normal plant growth and productivity (Leopold 1963; Street and Opik 1970). The reductions in yield measurements in the present study were probably due to the removal of these materials from the plants and not due to the salivary secretions of the pea aphid which appear not to be toxic (Mittler and Sylvester 1961). As expected, there was a tendency for decreased values for the parameters of yield with increases in infestation level, although the differences were not usually significant, probably because feeding lasted from 30 to 75 days, a period during which aphids at all infestation levels increased to very damaging levels. The consistent trend in both years, however, indicates that aphid damage to plants increased with increases in infestation levels.

Protein content of the seeds was not reduced by aphid feeding. Theses results are similar to those reported for forage alfalfa by Cuperus et al. (1982) and Harper and Kaldy (1982). In contrast, Barlow et al. (1977) reported overall lower protein content in infested than noninfested leaf and stem tissue of pea plants, after 11 days of aphid feeding. In the present study, some seeds from infested plants had more protein than those from noninfested plants (Table 7). Barlow et al. (1977) found higher protein content in stem tissue of some infested plants than in noninfested plants. The cause of this increase is unknown but it might be due to the interference with normal partitioning of plant nutrients among various plant parts (Mittler and Sylvester 1961; Pettit and Smilowitz 1982).

The apparent increase in yield of dry matter at higher aphid densities during the pod filling stage in 1981 is unexplainable. A low level of aphid infestation may stimulate vegetative growth, but as the duration or size of infestations increase, the damage to the plant may cause a net reduction of dry matter. However, further investigations are necessary to test this hypothesis.

In both years, plants infested at the beginning of the experiments, and left unsprayed until harvest were more severely affected than plants on which feeding occurred for shorter periods. Similar results have been reported for other crops (Lee _et_ _al_. 1981; Parman and Wilson 1982). The similarity in yield between noninfested plants and plants infested only during the vegetative growth stage in 1982 indicates that aphid feeding during this stage alone does not affect yield.

In 1982, plants which were infested up to the flowering stage resumed vegetative growth after termination of aphid feeding. This might have contributed to the lack of significant differences in dry matter between these and noninfested plants or those infested only during the vegetative growth stage. The plants also matured two weeks later than the rest.

Nitrogen fixing capacity of the infested plants was affected, confirming reports by Sirur and Barlow (1984). This effect of aphid feeding on plants could result in a delayed additional loss to the farmer through reduced soil fertility, although such a loss is difficult to quantify.

Aphid densities inside the cages increased to very high levels in both years as compared to those normally observed in the field but densities which kill plants in commercial fields have been observed in Manitoba (R. Zimmer Agriculture Canada Research Station, Morden and A.G. Robinson, Department of Entomology, University of Manitoba, Personal Communication). Rapid increases to high aphid densities inside field cages have been reported (Frazer et al. 1981; Chambers et al. 1983), and these authors attributed such increases to predator exclusion. A similar conclusion could be drawn in the present study. The densities attained in this study were unrealistic but useful for defining the possible effects of aphid feeding on pea plants. The results indicate that aphid feeding during the vegetative stage alone had no impact on yield. There were also high correlations between seed yield and number of pods per plant, seeds per pod and seed weight than dry weight of the plants. This suggests that yield loss occurs primarily as a result of direct feeding injury to flowers and pods. Population studies (Section 1) indicated that aphid populations during the vegetative growth stage are usually low but start to increase during flowering and pod filling growth stages. Therefore, these results suggest that these stages are the ones requiring protection if good yields are to be obtained.

SECTION III

Damage by the Pea Aphid, Acyrthosiphon pisum (Harris), (Homoptera: Aphididae) to Flowers and Pods of the Pea Plant, Pisum sativum (L.).

ABSTRACT

Flowers and pods in sleeve cages were infested in the field with different densities of the pea aphid, Acyrthosiphon pisum (Harris), for 4 days. Aphid feeding on flowers affected primarily the size of the pods. Feeding on young pods had a greater impact on yield components than feeding on flowers or later pod stages, regardless of infestation level. Infestation of filling pods did not greatly affect yield components. The results indicated that flowers, and young and enlarged flat pods are very susceptible to direct feeding damage.

1. Introduction

Feeding damage by the pea aphid, Acyrthosiphon pisum (Harris), on alfalfa, Medicago sativa (L.) and peas, Pisum sativum (L.), growing under field conditions, and the economic importance of the damage have been reported (Carnahan et al. 1963; Beirne 1972; Harper and Feryman 1979; Harper and Kaldy 1982). Damage to young pea plants under laboratory conditions resulting in reduced vegetative growth and nitrogen fixation have also been reported (Barlow et al. 1977; Barlow and Messmer 1982; Sirur and Barlow 1984), but no data have been published on the damage caused by the pea aphid to flowers and pods of pea plants.

Results from studies on whole plants (Section 2) indicate that feeding by the pea aphid during flowering and pod formation stages causes significant reductions in yield. However, the stage of development of the fruiting structures at which damage occurs was not revealed. The purpose of this study was to determine the effect of feeding by the pea aphid on flowers and pods of pea plants.

2. Materials and Methods

The experiments were conducted at the Agriculture Canada Research Station, Winnipeg, during the summer of 1983. Pea plants (cv. Century) were seeded in three adjacent plots, each with 4 rows, 30 cm apart and 10 m long. The plots were seeded at weekly intervals so that the fruiting structures were formed over an extended period and available for experiments. Seedings were done with a Bolens continuous seeder on 16 and 24 May, and 1 June 1983.

After germination, plants were thinned to 13 plants/metre of row and sprayed as required with 0.75 l a.i/ha of malathion to prevent aphid infestations. Flowers and pods were caged in cages made of insulated copper wire and a sleeve of fine nylon net which allowed circulation of air and prevented condensation (Fig. 13). Two wire rings, each 7 cm in diameter and joined by a 10 cm length of wire, were placed in a net sleeve to prevent the sides of the cages from collapsing. A pair of flowers or pods was inserted into the cage through one sleeve which was then tied loosely around the peduncle with string. After infestation, the second sleeve was tightly tied and the cage was supported on a wooden stake.

Each peduncle of a pea plant bears two flowers or two pods, so each cage contained two fruiting structures. Also the pea plant forms a pair of flowers or pods at intervals, so that different pairs of flowers or pods of the same age could only be obtained from different plants.

The categories of fruiting structures which were caged were: 1. flower buds, 2. young pods, 3. enlarged flat pods and 4. filling pods. Flower buds which were about to open were selected for caging. Young pods included pods which were one day old and less than 2 cm long, enlarged flat pods included those which were 5 to 6 cm long with no apparent seeds and filling pods were those with apparent seeds which were round and soft when compresed between finger and thumb.

Fig. 13. Sleeve cage used to confine pea aphids on flowers and pods of peas (cv. Century).

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Pea aphids for the infestations were reared as previously described (Section 2). Infestation of flowers and pod stages were conducted as separate experiments, each experiment using a completely randomized design with 7 treatments (densities) replicated 7 times (2 fruiting structures/replicate). A survey of the infestation on 50 samples of each category of fruiting structure in the field indicated that aphid numbers on the fruiting structures ranged from 0 to 70, with means±s.d. of 1.04 ± 2.42, 6.44 ± 10.32, 9.76 ± 9.65, and 4.10 ± 4.70 for categories 1 to 4. The infestation levels (treatments) used in this study (Tables 15, 17, 19, and 21) covered the range of aphid densities per flower or pod that occurred in the field. The aphids on the fruiting structures in the field consisted of all age groups and morphs but in the experiments, a 1:1 ratio of apterous adults and IV instar nymphs were introduced at each infestation level. Observations in an earlier study (Section 1) indicated that the period from flower opening to the appearance of a pod, and from one pod stage to another during the early stages, took approximately 4 days. Therefore in each experiment, aphid feeding was only allowed for this period.

After each experiment the cages were removed and the aphids in each cage were collected and stored in small plastic vials containing 65% alcohol. All fruiting structures in that experiment were then sprayed with 0.75 l a.i./ha of malathion to kill any remaining aphids and were left to mature. The plants and pods were checked regularly for aphids and any aphids found were killed by another application of malathion.

At maturity, the pods were hand harvested and the following data were recorded: pod length, number of seeds per pod, total seed weight, percentage of pods shed and percentage of pods shrivelled. Pod length was only measured for pods from caged flowers and young pods because the maximum length of a pod is attained at the enlarged flat pod stage.

Correlation coefficients between aphids introduced or removed and yield components were calculated using SAS (SAS Institute 1982). A significance level of $P \leq 0.05$ was adopted unless otherwise stated.

3. Results

The aphid densities and feeding durations used in this study did not cause flower shedding. Although all flowers formed pods, the pods from infested flowers were shorter and total seed weight was lower than for noninfested flowers (Table 15). No shrivelled pods developed from any of the flowers. However, a greater percentage of pods from infested than noninfested flowers was shed. The negative correlations (Table 16) between aphids introduced or removed and the various components of yield indicate that there was a trend towards decreased yield with increase in infestation levels. However, only the correlations between numbers of aphids and pod length were significant, thus indicating that aphid feeding on flowers primarily affected the size of the pods. There were significant positive correlations between pod length and number of seeds per pod, and seeds per pod and total seed weight.

Table 15. Effect of feeding by 7 densities of pea aphids on flowers of peas (cv. Century) at Winnipeg, Manitoba, 1983.

	Initial infestation level (aphids/cage)							
Yield Component	0	4	8	12	16	20	24	S.E.
Pod length (cm)[1]	5.66	5.07	5.40	5.06	4.80	5.03	4.57	0.17
Seeds/pod[1]	5.57	4.50	5.50	5.50	4.71	5.85	5.17	0.11
Single seed wt. (g)	0.24	0.22	0.24	0.23	0.23	0.25	0.20	0.02
Total seed wt. (g)[1]	2.28	1.71	2.10	1.99	1.69	1.94	2.03	0.27
Pods shed (%)	14.28	0.00	42.85	28.57	21.42	28.57	21.42	-
Shrivelled pods (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

[1] For pods with mature seeds.

Table 16. Correlation coefficients for yield components of peas (cv. Century) and infestations of pea aphids on flowers at Winnipeg, Manitoba, 1983.

	Parameter				
Parameter	Aphids Introduced	Aphids Removed	Pod Length	Total Seed Weight	Single Seed Weight
Seeds/pod	-0.036	-0.028	0.538[1]	0.892[1]	-0.275[1]
Single seed wt.	-0.086	-0.140	0.167	0.157	
Total seed wt.	-0.118	-0.062	0.621[1]		
Pod length	-0.559[1]	-0.576[1]			
Aphids removed	0.905[1]				

[1] Significant at $P \leq 0.05$.

Feeding on young pods affected all yield components (Table 17). The correlations between aphids introduced or removed and pod length, seeds per pod and total seed weight were negative and significant (Table 18). There were significant positive correlations between pod length and seeds per pod, seeds per pod and total seed weight, and individual seed weight and total seed weight.

When the enlarged flat pods were infested, all yield components except percentage of pods shed were affected (Table 19). The correlations between aphids introduced or removed and the various yield components were negative but only those for the two measures of aphid density and seeds per pod or total seed weight were significant (Table 20). The relationships between seeds per pod and total seed weight, and individual seed weight and total seed weight were similar to those in the flowers and young pod experiments. However, the correlation between individual seed weight and total seed weight in this case was stronger.

Aphid feeding on filling pods did not greatly affect yield components (Table 21). Although the correlation coefficients between aphids introduced or removed and the yield components were negative (Table 22), only that between aphids removed and total seed weight was significant. Other relationships were similar to those in the flowers, young, and enlarged flat pod experiments.

Table 17. Effect of feeding by 7 densities of pea aphids on young pods of peas (cv. Century) at Winnipeg, Manitoba, 1983.

Yield Component	Initial infestation level (aphids/cage)							
	0	4	8	12	16	20	24	S.E.
Pod length (cm)[1]	5.41	4.53	5.02	4.87	4.54	4.41	3.84	0.31
Seeds/pod[1]	3.28	1.57	1.78	2.42	1.07	1.07	0.14	0.53
Single seed wt. (g)	0.23	0.22	0.20	0.22	0.21	0.19	0.07	0.02
Total seed wt. (g)[1]	1.48	0.63	0.77	1.06	0.45	0.42	0.07	0.24
Pods shed (%)	0.00	14.28	7.14	7.14	21.42	14.28	7.14	-
Shrivelled pods (%)	7.14	28.57	28.57	28.57	35.71	42.85	78.57	-

[1] For pods with mature seeds.

Table 18. Correlation coefficients for yield components of peas (cv. Century) and infestations of pea aphids on young pods at Winnipeg, Manitoba, 1983.

Parameter	Parameter				
	Aphids Introduced	Aphids Removed	Pod Length	Total Seed Weight	Single Seed Weight
Seeds/pod	-0.516[1]	-0.565[1]	0.843[1]	0.974[1]	0.246
Single seed wt.	-0.167	-0.214	0.186	0.338[1]	
Total seed wt.	-0.491[1]	-0.527[1]	0.797[1]		
Pod length	-0.439[1]	-0.507[1]			
Aphids removed	0.934[1]				

[1] Significant at $P \leq 0.05$.

Table 19. Effect of feeding by 7 densities of pea aphids on enlarged flat pods of peas (cv. Century) at Winnipeg, Manitoba, 1983.

	Initial infestation level (aphids/cage)							
Yield Component	0	4	8	12	16	20	24	S.E.
Seeds/pod[1]	4.21	3.57	3.42	2.50	2.71	2.78	2.28	0.44
Single seed wt. (g)	0.21	0.21	0.18	0.20	0.20	0.18	0.20	0.01
Total seed wt. (g)[1]	1.79	1.51	1.22	0.97	1.09	1.10	0.92	0.19
Pods shed (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Shrivelled pods (%)	0.00	0.00	7.14	21.42	14.28	0.00	7.14	-

[1] For pods with mature seeds.

Table 20. Correlation coefficients for yield components of peas (cv. Century) and infestations of pea aphids on enlarged flat pods at Winnipeg, Manitoba, 1983.

	Parameter			
Parameter	Aphids Introduced	Aphids Removed	Total Seed Weight	Single Seed Weight
Seeds/pod	-0.443[1]	-0.525[1]	0.929[1]	0.057
Single seed wt.	-0.122	-0.167	0.363[1]	
Total seed wt.	-0.462[1]	-0.535[1]		
Aphids removed	0.910[1]			

[1] Significant at $P \leq 0.05$.

Table 21. Effect of feeding by 7 densities of pea aphids on filling pods of peas (cv. Century) at Winnipeg, Manitoba, 1983.

	Initial infestation level (aphids/cage)							
Yield Component	0	4	8	12	16	20	24	S.E.
Seeds/pod[1]	4.92	4.85	5.07	4.57	4.71	4.36	4.43	0.38
Single seed wt. (g)	0.21	0.20	0.21	0.20	0.21	0.21	0.18	0.01
Total seed wt. (g)[1]	2.04	1.91	2.18	1.81	1.98	1.78	1.64	0.20
Pods shed (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-
Shrivelled pods (%)	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-

[1] For pods with mature seeds.

Table 22. Correlation coefficients for yield components of peas (cv. Century) and infestations of pea aphids on filling pods at Winnipeg, Manitoba, 1983.

	Parameter			
Parameter	Aphids Introduced	Aphids Removed	Total Seed Weight	Single Seed Weight
Seeds/pod	-0.185	-0.267	0.818[1]	0.091
Single seed wt.	-0.147	-0.161	0.633[1]	
Total seed wt.	-0.231	-0.274[1]		
Aphids removed	0.714[1]			

[1] Significant at $P \leq 0.05$.

4. Discussion

Growth and enlargement of fruiting structures is accomplished through cell division and expansion, in the presence of auxins and photosynthates (Street and Opik 1970). Feeding by the pea aphid is known to remove auxins and nutrients from the plant, thus resulting in retardation of growth of the plant or plant structures (Maxwell and Painter 1962a & b; Harper and Kaldy 1978, 1982), while an imbalance between auxins and abscisins causes shedding of fruiting structures (Addicott 1982). In the present study, flowers were not shed probably because the period between flower opening and the appearance of a pod is very short, and the densities of aphids used in the experiments could not cause enough hormonal imbalance to cause flower shedding. However, the length of the pods from infested flowers and young pods was greatly reduced. The reduction in pod length could be attributed to the removal of auxins and plant nutrients, or to the destruction of ovules and developing seeds, which are sources of auxins (Street and Opik 1970). The highly significant positive correlations between pod length and number of seeds per pod suggest that destruction of ovules and developing seeds could have caused a reduction in pod length, but the significance of the withdrawal of the auxins and nutrients cannot be ruled out. The decrease in auxin concentration as a result of these processes could have caused enough upset in the balance between auxins and abscisins to cause pod shedding. However, some flowers produced pods which were shed although not subjected to aphid feeding. Pod shedding may have been due to a cage effect on the flowers, possibly because the sleeves were tied too tightly around the peduncles in the flower experiment.

Fruit development following fertilization involves the enlargement of the ovary and receptacle and the growth of seeds to maturity. If the ovules or developing seeds (auxin producing sites) in a flower or young fruit (pod) are fed upon by aphids and the hormonal imbalance is not enough to cause pod shedding, the pods will grow to maturity. However, the number and weight of the seeds may be reduced. In the present study, feeding on flowers and pods at the three growth stages resulted in fewer seeds per pod, and consequently, a lower total seed weight. Individual seed weight was not greatly affected, except at higher densities during the young pod stage. This was probably because most of seed development occurred in the absence of aphids as feeding was only allowed for 4 days.

The correlations between aphid numbers and the various yield components were usually higher for young pods than for flowers or other pod stages. This suggests that the young pods were very susceptible to direct feeding damage. However, overall results suggest that flowers, young pods and enlarged flat pods should be protected from aphid damage to prevent yield loss.

SECTION IV

Spray Regimes and Economic Threshold for the Pea Aphid, Acyrthosiphon pisum (Harris), (Homoptera: Aphididae) in Field Peas in Manitoba

ABSTRACT

Various insecticidal spray regimes were applied in field plots in 1981, 1982 and 1983 to assess the importance of the timing of sprays and also cause variation in the density of pea aphids so that the effect of density on yield could be determined. Different spray regimes resulted in different aphid densities but applying the insecticide too early in the season resulted in increases in aphid numbers. The best time to apply insecticide was when 50-75% of the crop was in bloom and pods were beginning to form. The economic threshold was variable from season to season, but an economic threshold for the three seasons was calculated to be 8.9-12.2 aphids/sweep.

1. Introduction

Current recommendations on pest control emphasize the rational use of pesticides from both economic and ecological points of view. The economic approach demands that the cost of control should be less than the value of crop lost if no control is used. This involves decisions with respect to the timing of control methods, the selection of a suitable pesticide and the method of application (Headley 1972). The ecological approach demands that chemical control should be applied only when natural control is inadequate and pest numbers increase to economically damaging levels (Stern *et* al. 1959). Stern *et al*. (1959) developed the concept of "economic threshold" as a basis for deciding whether or not to apply chemical control.

In Manitoba the pea aphid, *Acyrthosiphon pisum* (Harris) invades field peas, *Pisum sativum* (L.), each year and the aphid populations sometimes reach densities which cause pea growers to use insecticidal control. Present recommendations for chemical control (Anonymous 1977, 1983, 1984) are not based on experiments which relate yield to pest density. Also there is no information on the stage of crop development at which chemical control should be applied to prevent yield loss.

The purpose of this study was to determine the stage of crop development and the economic threshold at which chemical control should be implemented. The economic threshold was considered to be the pest density at which the value of the yield resulting from a control measure is equal to the cost of control (Edwards and Heath 1964; Headley 1973).

2. Materials and Methods

The experiments were conducted at Glenlea, a field station of the Agriculture Canada Research Station, Winnipeg. Field peas (cv. Century) were seeded in 3.6 x 5.0 m plots on 11 May 1981, 13 May 1982 and 16 May 1983. Adjacent plots were separated by 1.5 m paths in 1981, and 5 m paths in 1982 and 1983 to reduce interplot spray drift. The fields in which the experimental plots were located had been treated with Treflan granular herbicide and fertilized with 16:20:0NPK at recommended levels, based on a standard soil test. Seeding was done with a Bolens continuous seeder which seeded four rows at a time, the rows being approximately 30 cm apart. Plant density per unit area was not uniform in 1981 and 1982, but in 1983, plants were thinned to 13 plants/metre of row after germination. Weeds were controlled by hand hoeing.

Treatments consisted of insecticide applications made on the dates or during the crop stages (Section 1), shown in Tables 23-25, and were as follow: Bi-weekly sprays: 4 insecticide applications starting during the mid-vegetative stage (V_8), and continuing until the pod maturity stage (R_6). Flower spray: a single application when 50-75% of the plants had open flowers (R_2). Early pod spray: a single application when 50-75% of the plants had started forming pods (R_3). Flower and late pod filling sprays: two applications, one made on the same day as that of the flower spray (R_2) and the second applied two weeks later or when 50-75% of the plants had filled pods (R_4). Late pod filling spray: a single application made on the same day as the second application of the flower and late pod filling sprays. Control: no sprays. The treatments were designed to produce gradations in pea aphid populations, and were replicated 4 times in 1981 and 1982, and 6 times in 1983 in a complete randomized block design. The insecticide sprays consisted of 0.75 l a.i./ha of malathion, and the applications were made with a boom sprayer at a pressure of 3.17-4.23 kg/cm^2.

Aphid densities were monitored at approximately 14-day intervals in 1981 and 1982, starting a day before the first application of the bi-weekly sprays. In 1983, sampling was done twice, the first was done a week after the early pod spray and the second was done when 50-75% of the plants had pods starting to mature. Sampling consisted of 20 sweeps/plot/occasion, taken with a 38 cm diameter net with a 1 m handle. Each sweep was taken in a 180° arc through the tops of the plants. The aphids in each sample were stored in small plastic vials containing 65% alcohol for subsequent counting.

When the crop matured in 1981, each plot was machine harvested, and the seed yield and 1000 seed weight per plot were determined. Protein content of the seeds was determined (M. Hodgins, Agriculture Canada Research Station, Morden) by the Kjedhal method (AOAC 1975). In 1982, a 0.5 m^2 plot was marked in the centre of each plot and the number of plants in each sub-plot, and number of stems per plant were determined. The pods in each sub-plot were hand-picked and the following data were recorded: number of pods per plant, number of seeds per pod, 1000 seed weight, seed yield and protein content of the seeds. Observations indicated that the number of plants per sub-plot was variable, so in 1983, a 1m^2 plot was marked as in 1982 and pods were picked from 52 plants/sub-plot. Where 52 plants could not be obtained from within the sub-plot, more plants from the surrounding area were selected to make up the required number. This number of plants represented the plant density per 1m^2. Yield parameters were recorded as in 1982, but protein content of the seeds was not determined.

Samples of 20 plant tips and sweeps were taken in side by side transects from 5 areas of a farmer's field on 2 different dates in 1983, and from 4 areas on 4 different dates in 1984, and the number of aphids per sample unit was determined. The relationship between the number of aphids per sweep and aphids per tip was determined from these data.

Plants were also grown in 10 field cages in 1984, and were either not sprayed or sprayed with malathion at the same rate as in the previous experiments. At maturity, the pods were harvested and the 1000 seed weights from the two treatments were compared.

Data were analysed by analysis of variance using Agriculture Canada (Agrinet) computer programs, and by stepwise regressions (SAS Institute 1982). Means were compared by Duncan's new multiple range test (Steel and Torrie 1980). A significance level of $P \leq 0.05$ was adopted unless otherwise stated. Regression of yield parameters against number of aphids/20 sweeps/sampling occasion was conducted separately for each year. After selecting the dates on which aphid densities and yield parameters were most highly correlated, the data were pooled and further analysis incorporating total rainfall and cumulative degree days above 20°C was used because a day/night temperature regime of 27/17°C (Mean = 22°C) reduces the yield of peas (Nonnecke et al. 1971).

The relationship between the number of aphids per sweep and aphids per tip was determined by regression using the Hewlett Packard programs on an HP9815A programmable calculator.

The economic threshold was calculated by the method of Ogulana and Pedigo (1974) (Appendix 5). The following values for yield from commercial fields, crop price and control costs (Statistics Canada 1983, Mr. D. Smith, Entomologist, Manitoba Agriculture, Personal Communication), were used in the calculations. Yields from commercial fields were: 1950.25 kg/ha in 1981, 1835.95 kg/ha in 1982 and 1681.25 kg/ha in 1983. Crop prices were: \$0.24/kg in 1981, \$0.22/kg in 1982 and \$0.18/kg in 1983. Control costs were: \$15.75-22.00/ha in 1981, \$16.65-22.85/ha in 1982 and \$17.50-23.75/ha in 1983.

3. Results

Aphid populations were low in all plots throughout June, so only the dates with significant differences in aphid densities among treatments are presented. In 1981, significant differences in aphid numbers between treatments were first observed on 16 July (Table 23) when the plants were at the late pod filling stage (R_4). Plots sprayed biweekly had significantly fewer aphids than other plots on 16 July, but by 30 July, plots sprayed at late pod filling, or at flowering (R_2) and late pod filling stages had significantly fewer aphids than other

Table 23. Effect of malathion spray regimes on pea aphid populations and yields of peas (cv. Century) in field plots at Glenlea, Manitoba, 1981.

Spray regime	Date sprayed	Aphids/20 sweeps[1]		1000 seed wt. (g)	Seed Yield kg/ha	% Prot.[2]
		16 July	30 July			
Bi-weekly	11, 25 June, 10 July	4.50a[3]	69.25b	223.85a	2115.68a	21.90a
Flowers	6 July	11.00c	166.00c	222.61ab	2248.34a	21.95a
Flowers & pod filling	6, 18 July	7.25b	6.00a	222.53ab	2325.54a	22.68a
Pod filling	18 July	78.25e	10.00a	218.53b	2471.24a	22.28a
Control	-	43.00d	303.24d	218.83b	2292.92a	21.86a
S.E.	-	0.72	1.44	1.35	72.20	0.23

[1,2] Analysis of variance, and S.E. based on $\sqrt{x + 0.5}$ and Arcsine transformed data, respectively.

[3] Means followed by the same letter(s) within each column are not significantly different ($P \leq 0.05$), Duncan's multiple range test.

plots. Aphid numbers in plots sprayed bi-weekly or only at the flowering stage had increased by 30 July (Table 23).

Only the weight of 1000 seeds differed significantly among treatments (Table 23). Plots sprayed bi-weekly had the highest seed weight, followed by those sprayed only at flowering stage, or at flowering and late pod filling stages. The lowest seed weight was from unsprayed plots or those sprayed only at late pod filling stage. The variation in seed yield was not consistent with this trend.

In 1982, significant differences in aphid numbers between treatments were first observed on 12 July (Table 24). The plants were at the flowering stage and only the plots sprayed bi-weekly had been treated with insecticide. Aphid numbers in plots sprayed bi-weekly were significantly lower than those in plots which had not been sprayed by 12 July. By 28 July, the plants were at the pod maturity stage (R_6) and aphid numbers were lowest in plots sprayed bi-weekly, followed by those sprayed only at early pod stage (R_3), but by 28 July, aphid numbers in plots sprayed only at the flowering stage were not significantly different from those in unsprayed plots.

As in the previous year, only the differences in the 1000 seed weights were significant (Table 24). However, there was a trend for high values of the other yield parameters in plots sprayed bi-weekly. Plots sprayed at flowering and late pod filling stages, or only at early pod stage gave similar yields to those sprayed bi-weekly. Spraying only at flowering or late pod filling stage gave nearly as low yields as the control.

Aphid sampling in 1983 was delayed until 50-75% of the plants had filled pods and when the first sampling was done on 22 July, plots

Table 24. Effect of malathion spray regimes on pea aphid populations and yields of peas (cv. Century) in field plots at Glenlea, Manitoba, 1982.

Spray regime	Date sprayed	Aphids/20 sweeps[1]		Pods/ plant[2]	Seeds/ pod[3]	1000 Seed wt. (g)	Seed Yield (kg/ha)	% Prot.[4]
		12 July	28 July					
Bi-weekly	24 June, 8, 22 July & 5 August	27.25a[5]	22.50a	21.73a	4.06a	230.97a	2883.80a	21.47a
Flowers	12 July	201.75b	88.50cd	17.78a	3.67a	218.32b	2002.55a	21.52a
Early pods	16 July	227.50b	52.00b	18.35a	3.90a	225.81ab	2364.20a	20.82a
Flowers & pod filling	12, 28 July	253.75b	79.00bc	19.85a	3.99a	228.41ab	2744.00a	21.60a
Pod filling	28 July	230.00b	93.75cd	18.98a	3.94a	217.91b	2045.20a	22.20a
Control	-	198.00b	126.00d	17.05a	3.96a	217.77b	2181.00a	21.57a
S.E.	-	1.35	0.66	0.25	0.04	3.26	240.81	0.49

[1,2,3] Analysis of variance, and S.E. based on $\sqrt{x + 0.5}$ transformed data.

[4] Analysis of variance, and S.E. based on Arcsine transformed data.

[5] Means followed by the same letter(s) within each column are not significantly different ($P \leq 0.05$), by Duncan's multiple range test.

sprayed at flowering and late pod filling stages, or only at early pod stage, had significantly fewer aphids than those sprayed only at the flowering stage or those not sprayed (Table 25). Significant differences in aphid numbers were also observed on 5 August when the pods on most plants were starting to ripen. On that occasion, the fewest aphids were obtained from plots sprayed at flowering and late pod filling stages. Aphid numbers in plots sprayed only at flowering stage had increased and were not significantly different from those in control plots.

Seed weights from plots sprayed only at the early pod stage or at the flowering and late pod filling stages were significantly higher than that from unsprayed plots (Table 25). Other yield parameters tended to be highest either in the plots sprayed only at early pod filling stage or at flowering and late pod stages, but the differences were not statistically significant.

The 1000 seed weight from caged plants treated with malathion was 219.48 ± 1.55 g (mean±s.d.), (n=5) while that from unsprayed plants was 216.51 ± 2.42 g (n=5). The difference between treatments was not significant (t-test), thus indicating that malathion sprays did not have a significant effect on seed weight.

In 1981, seed weight was negatively related to aphid numbers on 16 July, but the relationship was not significant ($P<0.1$). In 1982, there was a linear relationship between aphid numbers on 28 July and 1000 seed weight ($S = 229.87 - 0.08X$, $r^2 = 0.20$, $n=24$) and seed yield ($Y = 2799.78 - 5.58X$, $r^2 = 0.18$, $n=24$). In 1983, aphids on 22 July and seed weight were related ($S = 223.52 - 0.06X$, $r^2 = 0.64$, $n=24$).

Table 25. Effect of malathion spray regimes on pea aphid populations and yields of peas (cv. Century) in field plots at Glenlea, Manitoba, 1983.

Spray regime	Date sprayed	Aphids/20 sweeps[1]		Pods/ plant[2]	Seeds/ pod[3]	1000 Seed wt. (g)	Seed Yield (kg/ha)
		22 July	5 August				
Flowers	8 July	168.66b[4]	475.83bc	7.68a	3.71a	214.93ab	2300.03a
Early pods	14 July	90.33ab	282.83ab	7.99a	3.52a	218.09a	2355.00a
Flowers & pod filling	8, 20 July	68.83a	196.16a	7.63a	4.46a	217.74a	2435.02a
Control	-	424.16c	550.16c	7.85a	3.61a	202.34b	2260.00a
S.E.	-	1.22	1.85	0.10	0.03	4.13	105.11

[1,2,3] Analysis of variance, and S.E. based on $\sqrt{x + 0.5}$ transformed data.

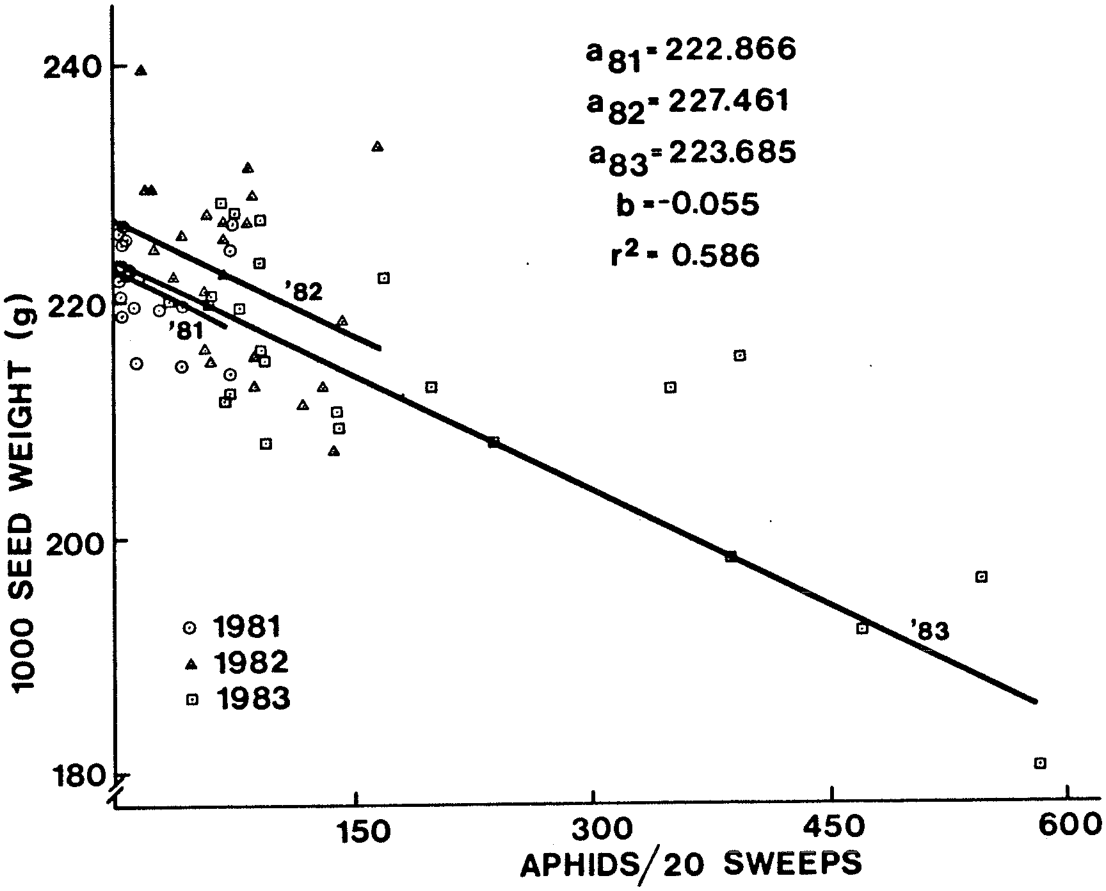
[4] Means followed by the same letter(s) within each column are not significantly different ($P \leq 0.05$) by Duncan's multiple range test.

The slopes for the yield parameters were significantly different between years (t-test, $P=0.001$), and the range of aphid densities in the three years varied greatly. A linear relationship ($S = 224.88 - 0.056X$, $r^2 = 0.54$, $n=68$) was obtained from analysis of the pooled data. Incorporation of total rainfall and cumulative degree days improved the relationship significantly ($P = 0.05$) and gave the equation $S = 190.69 - 0.055X_1 + 0.19X_2 + 0.11X_3$, $r^2 = 0.59$, $n=68$ where S is an estimate of seed weight, X_1 is the number of aphids/20 sweeps, and X_2 and X_3 are total rainfall and cumulative degree days above 20°C, respectively, for June and July. Substituting total rainfall and degree days into this equation gave different intercepts for each year, and the relationship between seed weight and aphid density on 16 July, 1981, 28 July, 1982 and 22 July, 1983 is shown in Fig. 14, with a separate line segment for each year. This relationship was used for calculation of economic thresholds.

The economic threshold was calculated to be 6.8-9.5 aphids/sweep in 1981, 8.50-11.7 aphids/sweep in 1982 and 11.5-15.5 aphids/sweep in 1983. The average price for peas during the three years was $0.21/kg, average control cost was $16.63-22.86/ha and an average economic threshold was calculated to be 8.9-12.2 aphids/sweep.

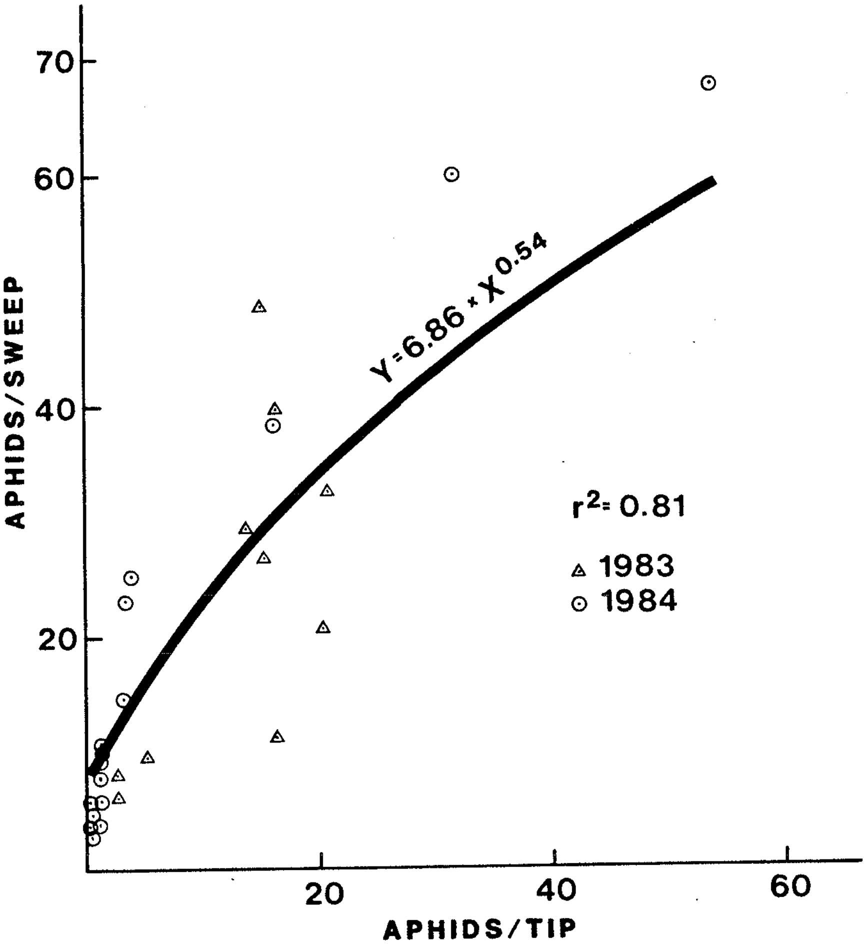
The number of aphids per tip and aphids per sweep were related ($Y = 3.44 \times X^{0.73}$, $r^2 = 0.58$, $n=10$) and ($Y = 7.59 \times X^{0.62}$, $r^2 = 0.93$, $n=16$), in 1983 and 1984, respectively, where Y is an estimate for the number of aphids per sweep and X is the number of aphids per tip. The slopes were not significantly different (t-test) and so the data were pooled for calculation of a common regression line $Y = 6.86 \times X^{0.54}$,

Fig. 14. Relationship between 1000 seed weight and number of aphids per 20 sweeps, 1981-1983.



a81 = 222.866
a82 = 227.461
a83 = 223.685
b = -0.055
r2 = 0.586
240
220
200
180
1000 SEED WEIGHT (g)
150
300
450
600
APHIDS/20 SWEEPS
'81
'82
'83
○ 1981
▲ 1982
▫ 1983

Fig. 15. Relationship between the number of aphids per sweep and the number of aphids per tip in field peas, 1983-1984.


70
60
40
20
APHIDS/SWEEP
Y=6.86 × X^0.54
r²= 0.81
1983
1984
20
40
60
APHIDS/TIP

$r^2 = 0.81$, n=26 (Fig. 15). From this equation, an economic threshold of 8.9-12.2 aphids/sweep is equivalent to 1.6-2.9 aphids/tip.

4. Discussion

The differences observed in numbers of aphids between spray regimes were a result of exposure of the aphids to the insecticide at different points in the seasonal cycle of population growth. Similar differences in populations of pea aphids in alfalfa were obtained by Cuperus _et al_. (1982) after applying different rates of insecticides at different times in the season. The increase in aphid numbers in plots receiving a single insecticide spray at the flowering stage was probably a result of pest resurgence as observed for other crop pests (Smith and Hagen 1959; Van den Bosch and Stern 1962). Pest resurgence might have also occurred in plots receiving bi-weekly sprays in 1981. In that year, the fourth spray was to be applied on 25 July but due to heavy rainfall, it was not applied. This might have provided enough time for the population to build up, thus resulting in higher aphid numbers on 30 July than 16 July.

In 1982 the number of pods per plant was higher than in 1983, although seed yield differences between the years were not as great. The high number of pods per plant was probably a result of more branching of the plants in 1982 than in 1983. Plant counts in 1982 indicated that there were about 10-15 plants/$0.5m^2$. In 1983, plants were thinned to 52 plants/m^2 but cutworm damage reduced plant density in some plots. Plant counts indicated that there were 45-52 plants/m^2. There were also 82.6 mm of rainfall during June and July of 1982 as compared to 22.1 mm for the same period in 1983. The low plant density per unit area together with the high rainfall in 1982 might have caused branching of the plants, thus resulting in more potential pod producing stems. It is also possible that the dry hot summer in 1983 might have caused flower drop, thus resulting in fewer pods/plant, but since the plant density per unit area was higher than in 1982, total yield was not greatly reduced. Such effects of weather on the crop have the potential of confounding comparisons of aphid effect for different years.

In each year of the study, seed weight differed significantly among treatments. Since neither the number of seeds/pod nor the number of pods/plant varied among treatments, it might be expected that seed yield would show similar differences to those of seed weight. However, no significant differences in seed yield were observed among treatments, based on analysis of variance, although in two of the years there was a similar trend to that observed for seed weight. The lack of significant differences could be due to the inability of the analysis of variance to detect real differences given the level of variation in yield and the number of replications. Increasing the number of replicates would improve the precision of yield estimates and increase the power of the test, but such an increase was not practical in this study. Although the yield differences were not significant, it cannot be concluded that aphids do not reduce yields. Such a conclusion can lead to a type II error, an error which can be very costly (Toft and Shea 1983). The significant relationships between aphid density and seed yield, and the results of the cage study confirm that aphids affected yields.

Estimates of seed weight were considered more precise and therefore the relationship between aphids and 1000 seed weight was used to calculate the economic threshold. Since neither the number of seeds/pod nor the number of pods/plant were affected by the observed aphid densities, seed yield reduction was assumed to be directly related to the reduction in seed weight. It was also assumed that the densities of aphids observed at the pod filling stage, and used to obtain the seed weight-aphid density relationship for calculating the economic threshold, were closely related to the densities occurring at the early pod stage when most damage occurred (Section 3). The validity of this assumption is shown by the cost-benefit calculations in Table 26. In 1981 and 1982, the number of aphids at the flowering stage were below the calculated economic threshold while in 1983, aphid densities at the flowering stage were above the threshold. As expected, an early pod spray in 1981 and 1982 resulted in a net loss, while in 1983, one spray at the early pod stage resulted in a net gain. Therefore these calculations are consistent with the calculated economic threshold from the results observed in experimental plots between 1981 and 1983.

There was a different economic threshold for each year mainly due to differences in crop price, control costs, and yield potential, the latter being a result of differences in weather factors. Economic thresholds are known to vary from year to year depending on the changes that occur in their primary determinants (Poston _et_ _al_.

Table 26. Benefits from spraying with malathion at the early pod stage following different densities of pea aphids during the flowering stage, 1981-1983.

Year	Aphids/sweeps[2] at flowering	% Increase[1] in Seed Wt.	Benefits over cost of control ($/ha)
1981	0.4	1.72	-7.70 to -13.95
1982	8.1	3.69	-1.71 to - 7.96
1983	20.0	8.61	2.30 to 8.56

[1] % Increase over unsprayed plots.

1983). It appears therefore that giving single values for an economic threshold, and extrapolating such economic thresholds to other seasons may be inaccurate. Economic thresholds should probably be viewed as averages (as in this study), or a range of values should be provided based on insect damage and economic variables for a number of seasons.

The results indicate that timing of insecticide application is important in pea aphid control. Early application of insecticide is ineffective for protecting yield because aphid populations rebound within two to three weeks, while late application permits damage to young and enlarging pods. Farmers who spray the crop too early as a form of insurance, or too late, would lose more money than those who do not spray at all since the yield increase from such untimely insecticide applications would not be enough to offset the cost of chemical control. A single application of insecticide at the early pod stage gave as good 1000 seed weight as did the bi-weekly or flower and late pod filling sprays. Since the cost of applying more than one insecticide spray is greater than the cost of a single well timed insecticide spray, application of more than one insecticide spray would not be profitable. A single application of insecticide at the early pod stage (R_3) (Fig. 16), when there are 8.9-12.2 aphids/sweep (1.6-2.9 aphids/tip) or more would protect the crop from increasing aphid populations, thus resulting in profitable yield increases.

Fig. 16. Stage of development of the pea plant (cv. Century) at which control measures with malathion should be applied to prevent pea aphid damage.

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CHAPTER IV

GENERAL DISCUSSION

A major requirement of the integrated control concept is to apply chemical control only when natural control is inadequate or when pest numbers increase to economically damaging levels (Stern *et al*. 1959; Smith 1976). The timing of insecticide application requires knowledge of the population dynamics and economic threshold of the pest species, and the stage of crop growth at which damage resulting in reduced yield occurs. This thesis presents information on the populations of the pea aphid, *Acrythosiphon pisum* (Harris), in relation to crop phenology, the crop growth stages at which damage occurs, and the economic threshold for the pea aphid in field peas in Manitoba.

The studies indicate that the pattern of growth of aphid populations was the same at the two locations in all three years. Infestations started in late May or early June during the seedling growth stage but populations remained low throughout June. Aphid densities started to increase in the first half of July when the crop was at the flowering stage. Peak populations were reached in late July or early August when the crop was at the pod maturity growth stage, and were always followed by a sharp population decline.

The factors that inhibited population increase throughout June are not clearly understood. Low temperatures, high rainfall and natural enemies are known to inhibit the population increase of pea aphids (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971; Campbell 1974; Frazer <u>et</u> <u>al</u>. 1981). Although the influence of these factors was not studied, some observations suggest that they might be important in suppressing population increase of pea aphids in Manitoba. For example, in 1982, there was high rainfall during most of the summer and aphid populations were very low. In 1983, aphid populations were low throughout June and early July at both locations, but a rapid population increase was noticed at Winnipeg soon after aerial spraying for mosquito control. Insecticide applications are known to destroy parasites and predators, thus leading to increase in pest numbers (Smith and Hagen 1959; Van den Bosch and Stern 1962). The rapid increase in aphid populations was probably due to the destruction of the natural enemies. It therefore appears that high rainfall and natural enemies were important in inhibiting population increase. However, the influence of other factors e.g. disease, cannot be ruled out.

In the present study, a sharp population decline was noticed as the crop dried. There were also high numbers of alate aphids as the crop matured. Campbell (1974) observed similar patterns in alfalfa fields. Deterioration in plant quality enhances production of alate forms by the pea aphid (Sutherland 1967, 1969a & b), while reproduction and survival on mature plants are greatly reduced (Auclair 1966). The production of alate aphids ensures escape from deteriorating host plants to colonize new habitats (Cooke 1963; Hille Ris Lambers 1966; Lees 1966). Possibly emigration of winged aphids, low reproductive rates and high mortality of aphids as a result of deteriorating plant quality were important in causing the sharp population declines. Observation of population trends, and production of emigrants in plots at different stages of maturity would be useful in confirming this hypothesis.

The one annual peak in Manitoba pea aphid populations, as compared to two peaks reported elsewhere (Dunn and Wright 1955; Cooke 1963; Smith and Hagen 1966; Pass and Parr 1971), is probably due to the short crop season in Manitoba. The size of the peak was different from year to year, but not from location to location, except in 1983. Although the years and locations involved in the study were too few to allow generalizations about aphid population patterns and sizes over a long period and wide area, the results suggest that aphid populations might vary more beween years than between locations. Therefore in some years, aphid populations might be very low and damage to the crop would be minimal. On the other hand, if high aphid numbers are noticed at a location, other pea fields in the area would be expected to have similar aphid problems, other factors being equal. The results also indicate that peak populations are likely to be reached in late July or early August. This information is useful in predicting when control measures will be required, thus enabling a better allocation of resources for other farm activities.

Cage studies showed that damage to the plant resulting in reduced yield occurs particularly during flowering and the early pod stages. Aphid feeding during the vegetative stage alone did not result in reduced yields, and aphid populations in the field were usually low during the vegetative growth stage. Direct feeding on the reproductive structures caused more severe damage to flowers and young or enlarged flat pods than to more advanced pod stages. Based on these results and those from population studies, it can be concluded that peak populations are reached after the most sensitive growth stages are finished. However populations start to increase in early July when the crop is at the flowering stage and beginning to be sensitive to damage. Since aphid populations are known to increase to high levels within a short time (Dunn and Wright 1955; Cooke 1963), densities which can affect yield may be reached when the young and enlarged flat pods are still present. Prevention of rapid population increase during the young or enlarged flat pod stages is therefore necessary to protect the susceptible reproductive structures from severe damage.

Since pea aphid feeding withdraws plant nutrients and amino acids (Harper and Lilly 1966; Harvey _et al_. 1971; Kindler _et al_. 1971), it would be expected that protein content would be reduced. However, the results from the field cage and spray experiments indicate that pea aphid feeding does not affect protein content of the seeds. Similarly Cuperus _et al_. (1982) and Harper and Kaldy (1982) found no difference in protein content of infested and noninfested forage alfalfa. In contrast, Barlow _et al_. (1977) reported overall lower protein content in infested than noninfested leaf and stem tissue of young pea plants. The difference among studies may indicate that larger, more mature plants are better able to produce sufficient protein to sustain aphids and plant requirements than young pea plants.

Various insecticide regimes were applied in field plots to assess the importance of the timing of sprays and also to cause variation in the density of pea aphids so that the effect of density on yield could be determined. Applying the insecticide too early in the season results in rapid increases in aphid numbers, probably due to the destruction of natural enemies (Smith and Hagen 1959; Van den Bosch and Stern 1962). The resurgence of aphid densities after early application of insecticide indicates the importance of timing control measures so that the recovery of aphid populations does not occur when the crop is still at the susceptible stage. These results, together with the observed aphid population increase at Winnipeg in 1983 following aerial spray for mosquito control, and the rapid increase in numbers of aphids inside field cages suggest that predators and parasitoids are important in suppressing aphid populations in Manitoba. Insecticides should therefore be applied only when these agents are inadequate and pest numbers increase to economic threshold levels. In the case of pea aphids on field peas in Manitoba, the best time to assess aphid density and, if necessary, apply insecticide is when 50-75% of the crop is in bloom, and with pods beginning to form.

Although the different spray regimes resulted in different aphid numbers in field plots, no significant yield differences were detected by an analysis of variance. Possible reasons for the failure to detect yield differences and the consequences of accepting a false null hypothesis have been given (Section IV). Indeed regression analyses indicated that seed weight and seed yield were negatively correlated with aphid densities at pod filling and pod maturity. Since the results from cage studies indicated that aphid feeding during late plant growth stages does not cause as much yield reduction as feeding during flowering and young pod stages, the negative correlations between seed weight or seed yield and aphid numbers were indicative mainly of the damage that had occurred due to aphid feeding during early pod stages. The regressions also indicated that the aphid effect on 1000 seed weight varied from year to year, with a stronger seed weight-aphid density relationship in 1983 when there was a hot dry summer. This suggests that more damage from aphids is likely to occur in years that are hot and dry than in years with cool wet summers.

The differences in seed weight, together with variations in other primary determinants of thresholds (Poston *et al.* 1983) resulted in different economic thresholds from season to season. This is expected since economic thresholds vary from season to season or area to area (Stern *et al.* 1959; Poston *et al.* 1983). However, such variation makes it difficult to decide which threshold to recommend for use by farmers. This is a major limitation to the use of economic thresholds in pest control programs. A solution would be to determine economic thresholds for different seasons and areas, and use such thresholds for calculating an average economic threshold which would be widely applicable. Although this was attempted in the present study by combining results for three seasons, an economic threshold based on data from more seasons and more than one area should be the ultimate goal. Nevertheless, the thresholds reported here are a step towards that goal and should be of value in making decisions about whether or not an insecticide should be applied.

CHAPTER V

SUMMARY AND CONCLUSIONS

This study indicates that infestation of the pea crop by the pea aphid, Acyrthosiphon pisum (Harris) starts in late May or early June, when the plants are seedlings. However, populations of pea aphids remain low throughout June after which densities start to increase in early July when the plants are flowering and pods are beginning to form. Peak populations of pea aphids are reached in late July or early August when most pods are mature, and are always followed by rapid population declines. Peak populations are different from year to year, and possibly in years with wet, cool summers, rapid population increases do not occur and chemical control may not be necessary.

Aphid feeding reduces yields. However, feeding during the vegetative stage alone has no effect on yields. Yield loss occurs primarily as a result of direct feeding damage to flowers and young or enlarged flat pods. Protein content of the seeds is not affected by aphid feeding. However, a severe aphid infestation reduces the plant's ability to fix nitrogen.

Correct timing of an insecticide application is important in pea aphid control. Early application of an insecticide is ineffective for protecting yield because aphid populations can rebound within two to three weeks, while late application permits damage to young and enlarging pods. A single application of insecticide at the early pod stage will protect the crop from increasing aphid populations. The insecticide should be applied when there are 8.9-12.2 aphids, or more, per sweep (1.6-2.9 aphids per tip of a plant stem). Assuming that only seed weight is affected at aphid densities near the economic threshold, and that yield is related to seed weight, spraying according to this recommendation would increase yield by 4-9%.

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APPENDIX 1. Total rainfall, rainy days, degree days above 5.5°C and mean monthly temperatures for the months of June-August, 1981-1983.

		1981				1982				1983			
Location	Month	Rainfall (mm)	Rainy days	$\bar{X}$ Temp. °C	Degree days	Rainfall (mm)	Rainy days	$\bar{X}$ Temp. °C	Degree days	Rainfall (mm)	Rainy days	$\bar{X}$ Temp. °C	Degree days
Glenlea	June	97.70	17	15.90	303.50	64.10	14	13.40	236.80	81.70	11	19.50	342.50
	July	58.80	12	19.50	432.10	82.60	13	19.50	432.70	22.10	5	22.50	509.25
	Aug.	95.60	11	19.80	444.20	30.50	11	16.60	344.40	51.30	8	22.50	511.50
Winnipeg	June	90.40	16	16.00	314.30	54.20	13	13.60	242.60	139.20	13	17.10	347.50
	July	39.00	11	20.30	459.10	106.90	10	20.00	449.80	29.80	6	22.20	517.40
	Aug.	103.60	8	20.10	464.80	59.00	13	16.80	361.80	75.20	11	22.50	526.30

APPENDIX 2. Aphid population statistics for two locations, 1981 - 1983.

	GLENLEA - 1981										
	JUNE					JULY				AUGUST	
	1	8	15	22	29	6	13	21	27	3	10
N	200	200	200	50	50	50	50	50	50	50	50
MEAN	0.14	0.33	0.85	1.66	1.72	6.60	14.14	31.82	39.60	27.76	0.78
VAR	0.91	1.18	4.22	9.21	10.45	134.98	588.65	1248.89	1948.00	2030.23	2.87
SD	0.96	1.08	2.05	3.03	3.23	11.62	24.26	35.34	44.14	45.06	1.69
SE	0.07	0.08	0.15	0.43	0.46	1.64	3.43	5.00	6.24	6.37	0.24
MAX	1.00	9.00	13.00	10.00	18.00	53.00	142.00	148.00	160.00	224.00	9.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	WINNIPEG - 1981										
N	200	200	200	50	50	50	50	50	50	50	50
MEAN	0.04	0.64	3.77	3.30	2.92	6.00	12.96	13.16	17.56	24.62	3.90
VAR	0.06	4.63	45.39	31.72	32.61	134.12	377.51	189.52	598.17	718.44	48.42
SD	0.25	2.15	6.74	5.63	5.71	11.58	19.43	13.77	24.46	26.80	6.96
SE	0.02	0.15	0.48	0.80	0.81	1.64	2.75	1.95	3.46	3.79	0.98
MAX	3.00	20.00	69.00	21.00	32.00	62.00	105.00	61.00	135.00	134.00	44.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 2. (cont'd) Aphid population statistics for two locations, 1981 - 1983.

	MAY	JUNE						JULY				AUGUST	
	29	1	8	15	22	29	29	6	13	21	27	3	10
GLENLEA - 1982													
N	150	150	150	150	150	150	150	150	150	150	150	150	150
MEAN	0.03	0.20	0.22	0.31	1.08	3.63	2.76	5.61	9.00	9.19	4.42	0.74	0.70
VAR	0.04	1.82	1.34	1.61	8.67	42.05	40.69	148.72	338.24	185.04	69.25	6.33	2.86
SD	0.21	1.35	1.15	1.26	2.94	6.48	6.37	12.19	18.39	13.60	8.32	2.51	1.69
SE	0.02	0.11	0.09	0.10	0.24	0.53	0.52	0.99	1.50	1.11	0.68	0.20	0.14
MAX	2.00	11.00	10.00	8.00	19.00	40.00	38.00	107.00	127.00	85.00	53.00	18.00	9.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINNIPEG - 1982													
N	150	150	150	150	150	150	150	150	150	150	150	150	150
MEAN	0.11	1.12	1.06	2.23	2.56	3.35	1.72	1.12	1.97	4.78	6.60	1.96	1.81
VAR	0.20	22.70	9.67	28.67	28.38	31.06	26.06	7.54	37.46	60.84	73.39	18.30	11.30
SD	0.45	4.76	3.11	5.35	5.32	5.57	5.10	2.74	6.12	7.80	8.56	4.27	3.36
SE	0.03	0.38	0.25	0.43	0.43	0.46	0.42	0.22	0.49	0.63	0.69	0.35	0.27
MAX	3.00	42.00	20.00	49.00	49.00	38.00	35.00	21.00	61.00	49.00	54.00	36.00	33.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 2. (cont'd) Aphid population statistics for two locations, 1981 - 1983.

GLENLEA - 1983

	JUNE						JULY				AUGUST			
	1	7	14	21	28	28	6	12	19	27	3	10	17	24
N	150	150	150	150	150	150	100	100	100	100	100	100	100	100
MEAN	0.00	0.01	0.16	1.98	4.86	3.33	11.07	11.91	18.17	17.30	24.29	7.45	0.36	0.00
VAR	0.00	0.01	1.02	21.01	39.65	29.81	151.62	176.35	444.41	569.51	681.42	319.99	7.91	0.00
SD	0.00	0.08	1.01	4.58	6.30	5.46	12.31	13.28	21.08	23.86	26.10	17.89	2.81	0.00
SE	0.00	0.01	0.08	0.37	0.51	0.45	1.23	1.33	2.11	2.39	2.61	1.79	0.28	0.00
MAX	0.00	1.00	10.00	39.00	34.00	33.00	75.00	57.00	109.00	120.00	120.00	115.00	28.00	0.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
WINNIPEG - 1983														
N	150	150	150	150	150	150	100	100	100	100	100	100	100	100
MEAN	0.00	0.01	0.74	0.36	1.11	0.39	1.36	6.95	6.70	24.93	52.48	39.13	15.03	0.00
VAR	0.00	0.01	21.15	1.48	3.37	2.07	8.37	156.86	49.02	642.47	2798.21	3498.24	1792.96	0.00
SD	0.00	0.08	4.60	1.22	1.84	1.44	2.89	12.52	7.00	25.35	52.90	59.15	42.34	0.00
SE	0.00	0.01	0.38	0.10	0.15	0.12	0.29	1.25	0.70	2.53	5.43	5.91	4.23	0.00
MAX	0.00	1.00	46.00	13.00	10.00	10.00	20.00	84.00	33.00	173.00	345.00	242.00	289.00	0.00
MIN	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

APPENDIX 3. Sample sizes for adult aphids and nymphs at Winnipeg and Glenlea - 1981-1983.

		June					July				August		
		1	8	15	22	29	6	13	21	27	3	10	17
						1981							
Adult Aphids	Winnipeg	3	18	90	23	14	24	75	47	58	135	12	-
	Glenlea	7	9	18	11	20	21	64	141	150	80	5	-
Total Nymphs	Winnipeg	4	68	664	142	133	280	574	611	820	1096	183	-
	Glenlea	21	57	152	72	66	309	643	1450	1830	1308	34	-
						1982							
Adult Aphids	Winnipeg	17	6	51	19	29	31	32	149	126	23	41	-
	Glenlea	4	6	16	27	41	61	108	148	71	17	17	-
Total Nymphs	Winnipeg	168	154	284	365	229	137	261	568	814	271	230	-
	Glenlea	27	27	31	136	374	774	1242	2476	603	94	86	-
						1983							
Adult Aphids	Winnipeg	0	1	20	10	20	17	20	135	192	600	399	262
	Glenlea	0	1	7	31	78	73	121	200	171	344	136	5
Total Nymphs	Winnipeg	0	0	165	67	57	119	622	534	1988	4386	3514	1241
	Glenlea	0	0	17	266	421	1034	1049	1667	1559	2085	609	31
III & IV Instar Nymphs	Winnipeg	0	0	56	11	16	52	88	64	1021	714	1392	358
	Glenlea	0	0	6	67	81	245	457	406	639	373	264	18

APPENDIX 4. Growth statistics of the pea plant <u>Pisum sativum</u> (L.) (cv. Century) - 1983.

DATE	DAYS POST EMERGENCE	$\bar{X}$ ± STEM LENGTH (cm)	$\bar{X}$ ± NODES	$\bar{X}$ ± YOUNG SHOOTS	$\bar{X}$ ± LATERAL STEMS	$\bar{X}$ ± PAIRS OF SENESCENT LEAVES	$\bar{X}$ ± FLOWER BUDS	$\bar{X}$ ± OPEN FLOWERS	$\bar{X}$ ± SMALL PODS (<2cm long, 0.5cm wide)
May 30	2	5.25 ± 0.78	1.00 ± 0.00	-	-	-	-	-	-
June 6	9	9.43 ± 1.24	2.30 ± 0.45	-	-	-	-	-	-
14	17	18.22 ± 2.45	5.30 ± 0.45	1.11 ± 0.69	-	-	-	-	-
21	24	38.61 ± 2.51	8.80 ± 0.40	1.50 ± 0.92	0.60 ± 0.48	-	-	-	-
29	32	76.50 ± 5.22	13.30 ± 0.64	-	1.70 ± 1.00	1.30 ± 0.90	4.50 ± 0.80	-	-
July 7	40	106.27 ± 7.72	16.50 ± 1.02	-	1.90 ± 0.83	3.00 ± 1.34	7.90 ± 1.44	0.10 ± 0.30	-
12	45	122.68 ± 14.87	19.50 ± 0.80	-	1.90 ± 0.83	5.60 ± 2.37	4.30 ± 1.95	3.10 ± 1.37	1.10 ± 0.94
19	52	128.43 ± 6.78	21.11 ± 1.64	-	2.06 ± 0.66	9.50 ± 1.96	-	0.40 ± 0.80	0.80 ± 0.97
27	60	133.99 ± 11.68	21.90 ± 0.83	-	2.10 ± 1.57	14.90 ± 3.14	-	-	-
Aug 3	67	136.25 ± 11.25	21.93 ± 0.91	-	2.45 ± 1.61	18.64 ± 0,74	-	-	-
10	74	138.84 ± 14.35	22.00 ± 1.58	-	2.50 ± 1.57	19.20 ± 0.87	-	-	-
17	81	139.86 ± 23.37	22.01 ± 0.87	-	2.40 ± 0.66	22.01 ± 0.87	-	-	-

APPENDIX 4. (cont'd) Growth statistics of the pea plant *Pisum sativum* (L.) (cv. Century) - 1983.

DATE	$\bar{X}$ ± ENLARGED FLAT PODS (2-6 cm long, 0.5 - 1.3 cm wide)	$\bar{X}$ ± FILLING PODS	$\bar{X}$ ± MATURE RIPE PODS	$\bar{X}$ ± DRY PODS	% PLANTS WITH YOUNG SHOOTS	% PLANTS WITH LATERAL STEMS	% PLANTS WITH SENESCENT LEAVES	% PLANTS WITH FLOWER BUDS
May 30	-	-	-	-	-	-	-	-
June 6	-	-	-	-	-	-	-	-
14	-	-	-	-	80	-	-	-
21	-	-	-	-	80	60	-	-
29	-	-	-	-	-	80	60	80
July 7	-	-	-	-	-	100	90	100
12	1.60 ± 1.49	-	-	-	-	100	100	100
19	2.60 ± 1.80	5.20 ± 1.53	-	-	-	100	100	-
27	-	1.50 ± 1.02	6.3 ± 1.48	-	-	100	100	-
Aug 3	-	-	4.20 ± 1.05	1.02 ± 0.86	-	100	100	-
10	-	-	1.60 ± 0.60	6.10 ± 2.46	-	100	100	-
17	-	-	-	7.80 ± 2.67	-	100	100	-

APPENDIX 4. (cont'd) Growth statistics of the pea plant *Pisum sativum* (L.) (cv. Century) - 1983.

DATE	% PLANTS WITH OPEN FLOWERS	% PLANTS WITH SMALL PODS	% PLANTS WITH LARGE FLAT PODS	% PLANTS WITH FILLING PODS	% PLANTS WITH MATURE RIPE PODS	% PLANTS WITH DRY PODS	% NODES WITH SENESCENT LEAVES	% FLOWER BUDS	% OPEN FLOWERS	% SMALL PODS	% LARGE FLAT PODS	% FILLING PODS	% MATURE RIPE PODS	% DRY PODS
May 30	-	-	-	-	-	-	-	-	-	-	-	-	-	-
June 6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
14	-	-	-	-	-	-	-	-	-	-	-	-	-	-
21	-	-	-	-	-	-	-	-	-	-	-	-	-	-
29	-	-	-	-	-	-	9.66 ± 6.66	100	-	-	-	-	-	-
July 7	20	-	-	-	-	-	17.94 ± 7.81	98.0	2.00	-	-	-	-	-
12	90	60	60	-	-	-	29.13 ± 13.02	44.71	30.06	10.19	15.03	-	-	-
19	20	40	50	80	-	-	44.90 ± 8.30	-	3.96	10.05	16.53	69.74	-	-
27	-	-	-	80	60	-	68.35 ± 15.67	-	-	-	-	26.23	70.59	-
Aug 3	-	-	-	-	80	20	85.00 ± 8.75	-	-	-	-	-	80.00	20.00
10	-	-	-	-	10	90	96.25 ± 8.22	-	-	-	-	-	10.00	90.00
17	-	-	-	-	-	100	100.00 ± 0.0	-	-	-	-	-	-	100.00

APPENDIX 5. Method for calculating Economic Threshold.

1. Calculate how much produce is equivalent to the cost of control.

   i.e. $\frac{\text{Control cost (\$/ha)}}{\text{Price of produce (\$/kg)}}$ = Gain Threshold (kg/ha).

2. Express the Gain Threshold as a percent of the yield from a commercial crop.

   i.e. $\frac{\text{Gain Threshold (kg/ha)}}{\text{Yield from commercial crop (kg.ha)}} \times 100 = Z$

3. Determine the relationship between yield parameter and pest density by assuming a linear relationship in which yield parameter (Y) is related to pest density (X) by equation $Y = A - bX$.

4. Then the Economic Threshold (ET) = AZ/b.

Explanations:

If the Model $Y_i = A - bX_i$ is assumed to relate yield to pest density.

And if A represents the yield realized at zero pest density

i.e. A = Yield at X_0

Then for a control measure to be justifiable, A must be greater than the yield realized at some uncontrolled pest density X_i by some percent.

Suppose the yield at X_i is Y_i.

Then $A = Y_i$ + % increase over Y_i.

Similarly, $Y_i = A$ - % decrease on A or $Y_i = A$.

That percent is Z.

Thus $Y_i = A - Z$ of A.

Substituting this in the Model $Y_i = A - bX_i$ gives $A - ZA = A - bX_i$.

Since A, b and Z are known, X_i can be calculated by solving for X_i.

Solving for X_i gives equation $A - ZA - A = - bX_i$.

Simplifying this equation gives $ZA/b = X_i$.