# SEASONAL ABUNDANCE AND ECONOMIC INJURY LEVELS FOR DEFOLIATORS OF POTATO IN MANITOBA

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by

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# SEASONAL ABUNDANCE AND ECONOMIC INJURY LEVELS FOR DEFOLIATORS OF POTATO IN MANITOBA

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

DOCTOR OF PHILOSOPHY

Dedicated to my parents,

Sirisena Goonasekera

and

Chandralatha Dhanawathi Manike

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The University of Manitoba, 1986

Seasonal Abundance and Economic

Injury Levels for Defoliators

of Potato in Manitoba

Major Professor: N.J. Holliday

ABSTRACT

The study was conducted during the summer of 1983-1985 on an early maturing potato (Solanum tuberosum L.) cultivar Norland. In an experimental (insecticide free) plot, the densities of Colorado potato beetle, Leptinotarsa decemlineata (Say) and potato flea beetle, Epitrix cucumeris (Harris) were assessed by whole plant bag sampling (WPBS), visual and sweep-net sampling while potato leafhopper, Empoasca fabae (Harris) and aphids were assessed by WPBS and sweep-net sampling. WPBS was used as a standard method for comparing the efficiency of other sampling methods. Regressions of the visual or sweep-net estimates on WPBS were done for all species. Evaluation of precision, accuracy and seasonal change in bias showed that visual sampling can be used as an alternative to WPBS to estimate densities of Colorado potato beetle, whereas WPBS was more suitable for potato flea beetle. Sweep-net sampling of Colorado potato beetle, potato flea beetle, potato leafhopper, and aphids yielded estimates that varied in bias over the season.

Colorado potato beetle was found to be the most destructive species on potato. Complete defoliation of plants at high densities of Colorado potato beetle resulted in low densities or early decline of potato flea beetle, potato leafhopper and aphid populations. Growers' insecticide

applications were successful in controlling Colorado potato beetle populations but had very little effect on other potential insect pests.

The densities of Colorado potato beetle were manipulated on individually caged plants of the same cultivar so that throughout the growing season each plant was exposed to a constant ratio of the density in the experimental plot. The linear relationship between percent yield and density of larvae at the first bloom stage was used to estimate the economic injury level. The range of economic injury levels for varying control costs and yield potentials under Manitoba growing conditions was 0.14-1 larvae per plant.

Similar manipulations of potato flea beetle density in caged plants resulted in no significant depression of yield at up to twice field density. A cubic polynomial relationship between percent yield and peak adult density was obtained. The estimated range of the economic injury level at two weeks past first bloom is 67-75 feeding punctures on the undersurface of a bottom leaflet. The potato plant showed tolerance at low levels of defoliation to potato flea beetle but not to Colorado potato beetle. However, response of the plant to high levels of defoliation by these species was similar.

High densities of potato flea beetle increased the severity of common scab on potato. Feeding activities of the beetle larvae could have influenced the spread of scab pathogen, <u>Streptomyces scabies</u> (Thaxter) Waksman and Henrici on tubers.

# CHAPTER I

# INTRODUCTION

## 1.1 The pest problem

Potato, Solanum tuberosum L. is one of the six leading food plants of the world (Ewing 1981). In terms of total energy for human consumption, potato ranks fifth after wheat, maize, rice and barley (Radcliffe 1982). It is grown most extensively in USSR, Europe and North America, but to a lesser extent in Asia, Africa and South America (Ewing 1981). Total potato production in Canada is approximately 3 million metric tons annually (FAO 1983), to which Manitoba contributes 10 percent (Canada Department of Agriculture 1984).

Injury to the potato plant can be caused by numerous insect species (Painter 1951). In Manitoba, among the most important are the defoliators, Colorado potato beetle, Leptinotarsa decemlineata (Say) and potato flea beetle, Epitrix cucumeris (Harris); and the sap feeders potato leafhopper, Empoasca fabae (Harris), green peach aphid, Myzus persicae (Sulzer) and potato aphid, Macrosiphum euphorbiae (Thomas) (Cole 1951). Uncontrolled populations of Colorado potato beetle can completely destroy the crop before the end of the growing season (Ferro 1985). The ability of potato flea beetles (Schaal 1934) and aphids (Radcliffe 1982) to transmit virus and bacterial diseases further increases the importance of these species on potato.

The damage caused by defoliators is conspicuous and causes concern among growers, who frequently apply insecticides with little knowledge of pest numbers or of the economics of control measures. Although the impact of short periods of defoliation by Colorado potato beetle on potato yield has been studied (Hare 1980b; Cranshaw and Radcliffe 1980;

Shields and Wyman 1984), the effect of season-long defoliation is less well understood. Little is known about the effect of defoliation by potato flea beetle. Thus there are no good data which can be used as a basis for making decisions about the need for control of these two species on potatoes in Manitoba.

## 1.2 Objectives

This study has the following objectives:

i. To compare the visual, sweep-net and whole plant bag sampling methods for estimating population trends of insect pests on foliage.

ii. To determine the seasonal abundance of pests.

iii. To determine an economic injury level for Colorado potato beetle.

iv. To determine an economic injury level for potato flea beetle, and to compare the yield response of the plant to the two defoliators.

v. To determine the relationship of common scab to potato flea beetle infestations.

vi. To determine the within plant distribution of Colorado potato beetles.

vii.To examine the effect of insecticide spray timing on potato yield.

## 1.3 Approaches and Thesis Organization

The thesis is a report of research carried out in the field and in growth rooms from 1983 to 1986. Population studies were done in field plots at the Agriculture Canada Research Station in Morden, Manitoba and in nearby growers′ fields. Damage assessment studies were done in field cages on the campus of The University of Manitoba, Winnipeg.

Chapter II is a review of pertinent literature. Chapter III presents the methods and results of the experimental work in seven parts written in a style suitable for publication as a series of scientific papers. It is anticipated that Parts I, II, III and IV will be submitted to the Journal of Economic Entomology, and Part V to the American Potato Journal. Parts VI and VII may not be submitted to a journal, but are written in the style of the Journal of Economic Entomology. Chapter IV is a general discussion.

# CHAPTER II

# LITERATURE REVIEW

## 2.1 Some biological aspects of foliage dwelling insect pests on potato

### i. Colorado potato beetle

Potato, Solanum tuberosum L. is the principle host plant of Colorado potato beetle, Leptinotarsa decemlineata (Say) (Jermy 1961; Harcourt 1963; Hsiao and Fraenkel 1968; Latheef and Harcourt 1972; Hsiao 1978; Melville et al. 1985). The life cycle of the beetle on potato is well known (Gibson et al. 1925; Cole 1951; Ferro et al. 1983). Overwintering adults emerge from the soil in the spring when the potato plant is first breaking through the ground. The beetle fecundity is high; a female is capable of laying more than 3000 eggs (Brown et al. 1980; Peferoen et al. 1981). Eggs are laid in clusters on the underside of the leaves. The larvae pass through four instars and when mature drop to the ground (Jacques 1985), burrow into the soil and pupate. The summer adults emerge from the soil and walk to a potato plant (Ghidiu 1984). Both larvae and adults feed on the plant at 24$^{o}$C; the first instar larvae consume less than 2%; the second, 6%; the third, 19%; and the fourth, 73% of the total leaf area consumed by the larval stages, and adults for the first 10 days consume 2.5 times more food than all larval stages combined (Tamaki and Butt 1978; Ferro et al. 1985). Only the adults survive the winter, in the soil at a depth of 10 to 25cm, depending on soil type (Hodgson et al. 1974). Colorado potato beetle can complete three generations per year in Long Island (Wright 1984) as compared to one generation per year in northern Maine (Ferro 1985).

The population dynamics of Colorado potato beetle on potato (Harcourt 1964 and 1971) and tomato (Latheef and Harcourt 1973 and 1974) has been studied extensively in eastern Ontario. Colorado potato beetle populations do not undergo density dependent processes which might avoid over-exploitation of food resources. Once discovered, a food resource is quickly exploited and this is followed by mass starvation of the larvae, and emigration of the adults in quest of new hosts. However, a sufficient number of adults survives to perpetuate the local population and, if the resource is renewed on an annual basis (i.e. planted by man), beetle numbers increase and decrease resulting in many generations per year (Harcourt 1971).

The effect of physical factors on the dynamics of Colorado potato beetle is well studied (Harcourt 1971), including the influence of a single temperature (Latheef and Harcourt 1972; Tamaki and Butt 1978) or of several constant temperatures (Hurst 1975; Walgenbach and Wyman 1984a; Ferro et al 1985; Logan et al. 1985) on the growth of the beetle population. Optimum development of all stages occurs around 24-28$^{\circ}$C. Rainfall and mud splashing reduce hatchability of egg masses (Harcourt 1964 and 1971). During heavy downpours, first and second instar larvae are frequently washed from the leaves to the ground where they perish in small pools of surface water (Harcourt 1971).

Beetle populations are also affected by biotic factors. The parasitoides and predators include Doryphorophage doryphorae (Riley) (Tamaki et al. 1983a and b), Perillus bioculates (F.) (Tamaki and Butt 1978), Podius maculiventris (Say) (Drummond et al. 1984), pentatomids, coccinellids and chrysopids (Cole 1951). The effectiveness of D. doryphorae is limited by its low abundance in June and July, during the first generation of the Colorado potato beetle (Harcourt 1971; Tamaki et al. 1983a). Use of entomopathogenic fungi, especially Beauveria bassiana (Balsamo) alone (Anderson and Roberts 1983; Hare and Andreadis 1983; Loria et al. 1983; Watt and LeBrun 1984) or in combination with Paecilomyces fumosoroseus (Wize) (Bajan and Kmitowa 1969; Bajan 1973) to control Colorado potato beetle populations have been reported. These entomopathogens are pathogenic to all stages of the beetle and often result in considerable reductions in the population. The entomopathogenic bacterium Bacillus thuringiensis var. thuringiensis is effective against Colorado potato beetle (Cantwell and Cantelo 1984; Cantwell et al. 1983; LeBrun 1984); ingestion of bacteria by first and second instar larvae can result in 90% reduction in the population (Cantwell and Cantelo 1984).

ii. Potato flea beetle

Life history studies on potato flea beetle, Epitrix cucumeris (Harris) have been conducted by Johannsen (1913), Hanson (1933), Cannon (1949) and Cole (1951). In temperate regions the adults overwinter in protected places such as under leaves and along ditchbanks. They emerge in the spring and the females lay eggs in moist soil near the roots of host plants (Painter 1951; Antonelli 1978). The larvae pass through three instars, and feed mainly on roots but also attack the tubers of the potato plant. Two types of larval injury are observed on tubers (Cole 1951). The first type, which is most commonly encountered; is surface feeding leaving a network of fine tunnels. The second type leaves minute holes about 6.4 mm deep perpendicular to the tuber surface. The pupae develop in the soil from which emerge adult beetles. The adults feed on leaves and produce characteristic round holes and scars about 0.1 to 5.0 mm in diameter (Pond et al. 1978). The scars are a result of adults feeding on the upper surface or underside and never completely through the leaf (Johannsen 1913). There is more feeding injury on the under surface of the leaf (Cole 1951). In Canada, potato flea beetle has one to two generations per year on potatoes (Cannon 1949).

The population pattern of potato flea beetles shows two peaks coinciding with late spring and mid-summer adult populations (Hanson 1933; Cole 1951). The second peak is followed by a rapid decline in population with some of the beetles migrating from the potato stand. In late summer the beetles go into diapause and the number of beetles in samples approaches zero. Knowledge of the effect of physical factors and biotic factors on the population dynamics of potato flea beetle is limited.

### iii. Potato leafhopper

Detailed accounts of the life cycle of the potato leafhopper, *Empoasca fabae* (Harris) are given by Cannon (1948), Cole (1951) and DeLong (1971). A portion of the potato leafhopper population migrates northward each summer from the overwintering range in the Gulf region (Radcliffe 1982). Eggs are usually deposited in tender plant stems or in the underside of the leaf ribs or veins. Nymphs appear approximately

3 weeks after adult arrival. The nymphs pass through five instars. Both nymphs and adults feed by sucking the sap from vascular tissues. The injury caused is called "hopperburn", which is a physiological condition resulting from a combination of feeding and the action of the toxic saliva injected during feeding (Ladd and Rawlins 1965). No pathogens are involved in the process (Radcliffe 1982). The number of potato leafhopper generations per year is determined by the physiology of the host plant and the prevailing temperature, and may vary from one to five (DeLong 1971).

The population pattern of potato leafhopper is characterized by a relatively low peak in late May followed by a gradual increase to a second peak between mid-July and mid-August (Cole 1951; Cancelado and Radcliffe 1979a; Johnston 1981). The magnitude of the peaks depends to a large extent upon the geographic area and the type of host plant. For example in temperate regions long-season cultivars of potato or alfalfa regrowth after alfalfa is cut, furnish a long season of available green tender foliage upon which several populations can build up (DeLong 1971).

The prevailing weather conditions may affect potato leafhopper populations. Available water and humidity are very important for the survival of leafhoppers, which live entirely upon liquid foods (DeLong 1965). The eggs pass the incubation period at saturated humidity. After hatching, the nymphs and adults feed from the under surface of the leaf and live continuously in a highly humidified atmosphere (DeLong 1971). In North America, potato leafhoppers do not appear to have any effective natural enemies (Radcliffe 1982).

iv. Aphids

A considerable number of species of aphids have been reported as feeding on potatoes. A detailed review of the life cycle of these species is given by Radcliffe (1982). The two species most commonly reported in Manitoba on potato are the green peach aphid, *Myzus persicae* (Sulzer) and the potato aphid, *Macrosiphum euphorbiae* (Thomas) (Cole 1951). Both overwinter as fertilized ova on the primary host, which for *M. persicae* are various *Prunus* species and for *M. euphorbiae* are *Rosa* species (Cole 1951). In the spring the eggs hatch to give rise to a generation of wingless females (Cole 1951; MacGillivray 1979). These feed on new plant growth, then give birth to offspring that develop into both winged and wingless females. The winged females migrate and colonize summer hosts such as potatoes, where they produce only female nymphs. This parthenogenetic viviparous reproductive process of females producing females continues for many generations during the summer. In late August the winged females migrate to the primary host and produce wingless females and winged males. After mating the females lay the overwintering eggs on the leaves and stems of the primary host. The transition from one form to another is influenced by photoperiod, temperature, host plant condition and crowding (van Emden et al. 1969).

Injury to plants by aphids may result from one or a combination of the following: reduction in plant sap due to aphid feeding, toxic action of salivary secretions, and virus transmission (Swenson 1968; Mackinnon 1969; Landis et al. 1972; Gibson 1974; Mackinnon 1974; Manzer et al. 1977; Leonard and Holbrook 1978; Sylvester 1980; Carlebach et al.

1982 and many others). The primary importance of aphids attacking potatoes is as vectors of virus diseases, but high populations can result in substantial direct losses. Symptoms of infection vary with the virus or combination of viruses involved, rate of multiplication of the pathogen, physiological age of the plant at the time of innoculation, and environmental and cultivar differences (Radcliffe 1982). At least nine viruses or virus-like diseases of potatoes are aphid transmitted; of these potato leaf roll virus (PLRV) is the most important (Radcliffe 1982).

In Minnesota the population pattern of aphids is characterized by relatively low densities in spring and early summer, and then a gradual or rapid increase to a peak in mid- or late-summer (Cancelado and Radcliffe 1979b; Johnston 1981). Phenology of the aphids can be related to plant phenology; high densities of aphids are found on plants that senesce early in the growing season (Bradley 1952; Shands et al. 1954; Taylor 1955). Aphids require amino-nitrogen compounds mobilized during leaf senescence (Kennedy 1958; van Emden 1966), and the fecundity of aphids increases with increasing plant nitrogen content (Woolridge and Harrison 1968). These factors probably account for the more rapid increase in aphid populations on early-season cultivars than on longer-season cultivars (Jansson and Smilowitz 1985a, b).

The effects of physical factors such as temperature, photoperiod, precipitation and wind may influence aphid populations (van Emden et al. 1969). Low rainfall results in high populations (Taylor 1955). Heavy rains and strong winds wash or shake the aphids off the plants (Cole 1951). Temperature affects aphid populations directly (Whalon and Smilowitz 1979; Tamaki et al. 1982) or indirectly through its effect on biotic factors (Soper 1981).

Biological control of aphids by parasitoids, predators and pathogens is described by Radcliffe (1982). Numerous parasitoid species, mostly aphidiids and aphelinids, are associated with potato infesting aphids (MacGillvray and Spicer 1953; van Emden et al. 1969), but apparently none are host specific, a prime prerequisite for effective biological control (Radcliffe 1982). Coccinellids, syrphids, chrysopids, anthocorids, nabids, and lygaeids are the most important taxa of aphid predators and these appear to be more effective than parasitoids when attacking the aphids on the primary hosts (Radcliffe 1982). A complex of entomopathogenic fungi attack potato-infesting aphids (Soper 1981). Factors essential for initiation of entomopathogenic epizootics include favorable climatic conditions especially high humidity, amount and distribution of inoculum, and host density and degree of aggregation.

## 2.2 Impact of defoliators on yield

The impact of Colorado potato beetle defoliation on potato yield has been examined using data from natural insect defoliation studies (Hare 1980b; Ferro et al. 1983), and mechanical defoliation studies based on simulated insect injury (Cranshaw and Radcliffe 1980; Wellik et al. 1981; Shields and Wyman 1984) and simulated hail injury (Murphy and Goven 1962; Beresford 1967). These studies collectively indicate that potatoes have considerable capacity to recover from defoliation. Plant recovery and yield effects are primarily influenced by the growth stage of the plant and the extent of defoliation at the time of injury.

Potatoes can tolerate more defoliation without yield loss from insect injury than from hail injury since hail not only removes leaflets, but also bruises and breaks stems. Also the possibility that injury by insects induces rapid plant growth (Dyer and Bokhari 1976) cannot be ignored. In any event, natural insect defoliation seems to be less debilitating than mechanical defoliation (Hare 1980). Also it is evident that equivalent amounts of defoliation by an insect that is clumped in distribution and confines most of its feeding to the top growth, as does the Colorado potato beetle, results in substantially greater injury than from an insect that is more uniformly distributed and does not confine its feeding to a particular portion of the plant (Cranshaw and Radcliffe 1980).

Little is known about the impact of potato flea beetle on yield. At high levels of defoliation, severe stress or death of the plant could result due to excessive evapotranspiration (Hodgson et al. 1974). Thompson (1984, 1985) in Prince Edward Island assessed the adult injury by counting all feeding holes in the fourth terminal leaflet. Five potato cultivars show significant reduction in yield when injury is 2894-5441 holes per leaflet (average for ten plants) in late August. The larvae feeding on tubers can affect their quality (Hanson 1933). However, at low levels of larval injury the lesions may remain unnoticed, unless they become infected with soil borne pathogens such as Streptomyces scabies (Thaxter) Waksman and Henrici (Hanson 1933).

## 2.3 Economic injury and economic threshold

### i. Definitions

Historically, economic entomologists have concerned themselves with preventing damage from insects (Pedigo et al. 1986). From this concern has come the concept of economic injury level and economic threshold which have been defined in a number of ways (e.g. Stern et al. 1959; Edwards and Heath 1964; National Academy of Sciences 1969; Headley 1973; Andow and Kiritani 1983; Posten et al. 1983). The most widely accepted definition is that presented by Stern et al. (1959). They restated and emphasized the relationship of pest numbers to damage as an "economic threshold (ET)". This was defined as "the density at which control measures should be applied to prevent an increasing pest population from reaching the economic injury level". The economic injury level (EIL) was defined as "the lowest population density that will cause economic damage", the economic damage being "the amount of injury which will justify the cost of artificial control measures".

The EIL always occurs at or beyond the damage boundary (the level of injury (or insect numbers used as an injury index) at which damage occurs) (Pedigo et al. 1986). Usually the ET occurs between the damage boundary and the EIL but in some instances the ET may be below the damage boundary. If the EIL is expressed in injury equivalents (which is the amount of injury that could be produced by one pest through its complete life cycle), the ET will always be below the EIL; but if the EIL is expressed in insect numbers and pest mortality is very significant, the ET may occur above the EIL (Pedigo et al. 1986).

The major advantage of the concept of EIL and ET is its simplicity and practicality in most situations. It was developed largely as a means for more rational use of insecticides (Pedigo et al. 1986). When there is no yield-pest density information available, growers rely on past experience to estimate ETs (Stern 1973). Such thresholds have no experimental basis for their determination and are termed "nominal thresholds" (Poston et al. 1983). Thresholds based on experimental evidence on the relationship between market value, insecticide costs, application costs and potential crop yield are termed "simple thresholds" (Poston et al. 1983).

The relationship used in estimating EILs may be linear or non-linear (Poston et al. 1983), but often a linear relationship is adopted because of its simplicity. Using a linear relationship the EIL can be calculated by the equation (Ogunlana and Pedigo 1974):

EIL = gain threshold (kg/ha)/b

where b = the7[Yof the regression line

$$\text{Gain threshold (kg/ha)} = \frac{\text{cost of pest control (\$/ha)}}{\text{market price of crop (\$/kg)}}$$

The ET is a direct function of the EIL and, as such, is subjected to changes in EIL variables (Pedigo et al. 1986). To establish ETs relative to EILs, some calculation must be made to determine an overall time delay based on the sum of individual delays (Ba-Angood and Stewart 1980). As the delay period increases, the distance between the EIL and ET also increases, resulting in a greater probability that the accelerating pest injury will not reach the EIL as anticipated (Pedigo et al. 1986). Therefore, the control tactic that has the shortest time delay (usually insecticides) probably will be the least risky (Pedigo et al. 1986).

ii. Economic injury and economic threshold for insect pests on potato

The method of cost benefit analysis has been used to establish the "simple threshold" for potato leafhopper (Cancelado and Radcliffe 1979a), green peach aphid (Cancelado and Radcliffe 1979b) and Colorado potato beetle (Ferro et al. 1983). Different pest densities were maintained in isolated plots by using different control regimes and infestations. Yields associated with each regime were calculated to determine the pest density at which maximum benefit was realized. A density of 10 potato leafhopper nymphs per 105 leaves (Cancelado and Radcliffe 1979a) and 30 apterous green peach aphids per 105 leaves (Cancelado and Radcliffe 1979b) are the appropriate levels for the application of insecticides in Minnesota. Ferro et al. (1983) in Massachusetts found that it is economically justifiable to control Colorado potato beetle summer larvae and adults on a medium-early maturing cultivar (Superior). Their data provide the data base for developing EIL and ET for Colorado potato beetle on early season potato cultivars.

"Nominal thresholds" have been reported for some potato pests in Canada (Coleman et al. 1983). Examples include: average of 2 Colorado potato beetles (adult or larvae) per plant in 12m of row, 10 potato flea beetles per plant or 15 holes per fourth terminal leaflet, 10 aphids per plant before or 25 aphids per plant after the second week of blooming (Coleman et al. 1983). Based on previous observations, Martel et al. (1986) considered an ET of 20 Colorado potato beetle larvae (third and fourth instars) per plant, for medium-maturing cultivars (Kennebec) to develop a sequential sampling plan in southwestern Quebec. However for some pest problems nominal thresholds could lead to insecticide applications that are not justified in terms of significant economic losses or no control when it is economically justified (Cothran and Summers 1974).

The economic impact of pests on potato (Cancelado and Radcliffe 1979a, b; Ferro et al. 1983) has been based on variables measured in a single season and extrapolated to other seasons. Although EILs and ETs have been based on the primary determinants such as (a) market price, (b) management cost, (c) injury per insect density, (d) host damage per unit of injury (Pedigo et al. 1986), no consideration has been given to the variability of such components.

# CHAPTER III

## PART I

## Comparison of visual, sweep-net and whole plant bag sampling for estimating insect pest populations on potato

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## ABSTRACT

Two monitoring methods, visual and sweep-net sampling, were evaluated for sampling Colorado potato beetle, *Leptinotarsa decemlineata* (Say) and potato flea beetle, *Epitrix cucumeris* (Harris); and sweep-net sampling was evaluated for monitoring potato leafhopper, *Empoasca fabae* (Harris) and aphids on potato. A whole plant bag sampling method (WPBS) was used as a standard sampling method for comparing the efficiency of the monitoring methods. Regressions of the visual or sweep-net estimates on numbers in corresponding WPBS allowed the conversion of densities of Colorado potato beetle, potato flea beetle, potato leafhopper and aphids estimated by one sampling method to equivalent levels from another, but did not correct for seasonal changes in bias. Evaluation of precision, accuracy and seasonal change in bias showed that visual sampling can be used as an alternative to WPBS to estimate densities of Colorado potato beetle, whereas WPBS was more suitable for potato flea beetle. Sweep-net sampling of all four species yielded estimates that varied in bias over the season.

# INTRODUCTION

Ecological studies and pest management sampling programs require precise and accurate estimates of insect densities. Precision refers to the magnitude of the deviations of sample estimates from their mean, and accuracy refers to the magnitude of deviations of the sample estimates from the population parameter being estimated (Fowler and Witter 1982). The accuracy of an estimate is almost always unknown, and can only be quantified when unbiased estimates or those with known bias are available (Southwood 1978).

Sampling methods providing an unbiased estimate of insect densities are usually time consuming and expensive. Thus a calibration equation that relates less labour-intensive estimates to unbiased density estimates is desirable for pest management programs. In potato pest management studies, estimation of insect density by visual examination of the whole plant or a portion of the plant is widely practiced (Harcourt 1964; Cancelado and Radcliffe 1979a, b; Lashomb and Ng 1984). However visual sampling has not been compared with alternative methods.

The present study examines the relative efficiencies of the visual and sweep-net sampling in estimating insect densities on potato. The results of whole plant bag sampling were assumed to be an unbiased estimate of absolute density (Byerly et al. 1978), and were used as a standard for the comparison.

MATERIALS AND METHODS

Sampling of potential insect pests on a plot of early-maturing potatoes cv. Norland was carried out at the Agriculture Canada Research Station at Morden, Manitoba during the summer of 1983, 1984 and 1985. In each year the plot consisted of 50 rows 1m apart and 30m long. The plot consisted of two sections; a centre section with 30 rows, and two outer sections with 10 rows each. In the outer sections, the commercial within-row plant spacing of 0.3m was used. In the centre section, plants were 0.6m apart to facilitate sampling.

A whole plant bag sampling method (WPBS) (Byerly et al. 1978) was used to estimate insect numbers in the centre section of the plot. WPBS of 15 randomly selected plants were taken each week throughout the season. Two weeks before sampling, a white cylindrical bag of nylon netting (28 meshes per cm), 1m in diameter and 1.5m long with a draw-string at each end, was lowered over the plant and folded flat on the ground so that it surrounded the base of the plant. On the day of sampling the lower draw-string was tightened around the base of the plant and the bag rapidly pulled up over the plant and closed at the top. The plant was then cut at ground level and the bag containing plant and insects was taken to the laboratory where potential pest insects were counted and recorded. The insects counted were of the following species: Colorado potato beetle, _Leptinotarsa decemlineata_ (Say); potato flea beetle, _Epitrix cucumeris_ (Harris); potato leafhopper, _Empoasca fabae_ (Harris). Aphids caught throughout each growing season were later identified as green peach aphid, _Myzus persicae_ (Sulzer) and potato aphid, _Macrosiphum euphorbiae_ (Thomas). During weekly sampling no attempt was made to identify aphids to species. To determine whether bags folded around plants attracted or repelled insects, each week in 1985 five randomly selected bags were covered with earth leaving only a 10cm margin exposed.

Visual sampling was used to determine the insect numbers in the centre section and the outer section of the plot in 1984 and 1985. Each week, the Colorado potato beetles and potato flea beetles were counted on 15 randomly selected plants from each section.

Sweep-net sampling was used to determine the insect numbers in the outer section of the plot in 1983. Each week, 25 complete (double) sweeps were made across the tops of two rows using a 0.38m diameter net with a 1m handle. The net was forced about 15-20 cm into the foliage. Insects caught were transferred into a small plastic bag and taken to the laboratory for counting.

Plant height was recorded weekly in each growing season. Fifteen plants were randomly selected and the height from the top of the hill to the highest growing point was measured.

Sampling methods were compared on the basis of the a priori assumption that the WPBS was an unbiased estimate of the absolute density of the insect species. Mean densities of WPBS were compared with estimates from visual samples from the centre section of the plot to evaluate their precision, accuracy and seasonal change in bias. Sweep-net samples were not replicated, thus only their seasonal change in bias was examined. A significance level of $P \leq 0.05$ was adopted unless otherwise stated.

# RESULTS

Estimates of the mean number of individuals per plant from WPBS and visual samples for the 1984 and 1985 seasons were: for Colorado potato beetle, WPBS 28.3 and 5.8, visual samples 19.4 and 4.7; for potato flea beetle, WPBS 20.9 and 23.6, visual samples 4.4 and 6.9. WPBS always yielded higher estimates than did visual sampling.

There was no effect of exposure of sample bags on WPBS estimates: estimates of mean density from covered and uncovered bag samples obtained for each species in 1985 (Appendix 1) did not differ significantly (unpaired t-test) when tested for each week. There was no evidence that any of the species were attracted or repelled by the bag.

Mean estimates of visual samples in the outer section and centre section of the plot (Appendix 2 and 3) were not significantly different (paired t-test) when tested for each week. These results indicate that densities per plant of Colorado potato beetle and potato flea beetle were not affected by the differences in plant density. The effect of plant density on the density of potato leafhoppers and aphids was not examined in the present study.

The coefficient of variation (CV) [(standard deviation/mean) 100] of WPBS and visual samples (Fig. 1) was used as a measure of precision of density estimates. In addition to a component due to variations in insect density between plants, CV also contains a component due to sampling error. The assumption that WPBS is without sampling error enables the examination of sampling error for other methods by comparison. The CV's of WPBS and visual samples for Colorado potato beetle were not significantly different (paired t-test) when tested over the whole season in 1984 ($t = 0.09$, $df = 7$) and 1985 ($t = 0.98$, $df = 9$).

In contrast, comparisons of potato flea beetle showed a significant difference (paired t-test) between the mean CV of WPBS (59.5) and of visual sampling (93.9) in 1984 ($t = 3.16$, $df = 7$), and WPBS (53.8) and visual sampling (102.1) in 1985 ($t = 2.42$, $df = 9$).

Regression of visual or sweepnet samples (Y) on WPBS (X) were performed for each species (Fig. 2A-F). The intercept was not significantly different from 0, thus the line was forced through the origin. There was a significant linear relationship between Colorado potato beetle numbers in WPBS and visual samples in 1984 ($Y = 0.68X$, $F = 127.6$, $df = 8$, $P \leq 0.0001$) and 1985 ($Y = 0.80X$, $F = 383.1$, $df = 10$, $P \leq 0.0001$). A relationship between WPBS and visual samples was also obtained for potato flea beetle in 1984 ($Y = 0.19X$, $F = 42.4$, $df = 8$, $P \leq 0.0003$) and 1985 ($Y = 0.26X$, $F = 55.7$, $df = 10$, $P \leq 0.0001$). The slopes were not significantly different between years and the data were pooled for calculation of a common regression line for each species (Fig. 2A and C). The relationship of the visual or sweepnet estimates as a linear function of the WPBS estimates was evident for all species. However, these regressions were based on season-long data, thus seasonal variation in bias was incorporated into the residual error.

The accuracy of visual estimates is indicated by the closeness of the gradient of the regression to 1. Visual sampling provided more accurate estimates of density for Colorado potato beetle than for potato flea beetle (Fig. 2A and C).

The predictions from the regression equations were examined for seasonal bias by calculating the percent bias of visual and sweep-net samples from, 100x[(predicted from the regression equation/observed)-1]. There was little change in bias in visual estimates of Colorado potato beetle (Fig. 3). However, a considerable change in bias was observed for visual samples of potato flea beetle (Fig. 3) and sweep-net samples of all species (Fig. 4).

Plants reached a maximum height in mid- or late-July (Fig. 5). Height decreased rapidly following the peak in 1983 and 1984. This is attributable to defoliation by Colorado potato beetles. The gradual decrease in height throughout August in 1985 is attributable to senescence.

# DISCUSSION

The evidence that WPBS yielded higher estimates than visual samples and also that the visibility of the bag and the plant density had no significant effect on insect estimates, do not contradict the assumption that WPBS provides an unbiased estimate of insect density.

The study provides calibration equations for Colorado potato beetle, potato flea beetle, potato leafhopper and aphids (Fig. 2A-F) that can be used to convert densities of insects obtained from one sampling method to equivalent levels in other sampling method but do not incorporate seasonal effects. For potato leafhoppers the observations were restricted to low densities (Fig. 2E) whereas for other species the observations were dispersed over a larger range. Since treatment decisions for potato leafhoppers are made at low densities (Cancelado and Radcliffe 1979a), this relationship is acceptable in pest management studies. Caution should be exercised when using the regressions outside these ranges, or at times when the seasonal bias is known to be high.

In sampling Colorado potato beetles, visual estimates were as precise as WPBS estimates. The parallel nature of the seasonal variation in precision for the two methods (Fig. 1) suggests that these are changes in aggregation behaviour, rather than changes in sampling precision. In 1984, low precision at the end of the season may be attributed to dispersal of larvae and adults due to complete defoliation of plants. Harcourt (1964) observed similar variations in precision of the visual estimates of Colorado potato beetle in Ontario. He standardized the plants and estimated CV for larvae and adults separately whereas in the present study the plants were allowed to develop their normal growth habitat and the CV was based on both larvae and adults.

Although the study showed that visual estimates were less accurate than WPBS of Colorado potato beetle(Fig. 2A) there was very little seasonal variation in bias (Fig. 3). Therefore the less time consuming visual method (WPBS requires 20 minutes per plant, while visual sampling requires 5 minutes per plant), when calibrated using the regression, is the most efficient method of obtaining unbiased density estimates.

In sampling potato flea beetles visual sampling provided less precise (Fig. 1) and less accurate (Fig. 2C) estimates than WPBS. The beetles' jumping habits and tendency to rest on the lower surface of leaves (Hanson 1933) could be responsible for the large variation in visual estimates. Also the considerable seasonal variation in bias (Fig. 3) makes it a less reliable technique for density estimation of this species.

Sweep-net sampling of all four species yielded estimates that varied in bias over the season (Fig. 4). Sweep-netting was more efficient early in the season (Fig 4) when plants were small (Fig. 5), probably because it sampled a large proportion of the insects on the plants. However this proportion declines (Fig. 4) with increasing height of the plant (Fig. 5). Complete defoliation of plants as occurred in late August in 1983 may be the reason for the increased efficiency of sweep-net sampling at that time.

The present study indicates that visual sampling can be used in place of WPBS in estimating Colorado potato beetle densities. Visual sampling is preferable to WPBS because it is less costly, less time consuming and easier. WPBS was found to be more precise and accurate in estimating potato flea beetle densities. The study also revealed that sweep-net sampling may not be a suitable method to estimate densities of Colorado potato beetle, potato flea beetle, potato leafhopper or aphids due to seasonal changes in bias. However, WPBS is too complex a method for use in routine monitoring. Therefore future studies should focus on developing a reliable sampling method for potato flea beetle, potato leafhopper and aphids, that can be easily used in making decisions in pest management programs.

## ACKNOWLEDGMENTS

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Figure 1. Coefficient of variation of WPBS and visual samples for Colorado potato beetle and potato flea beetle.

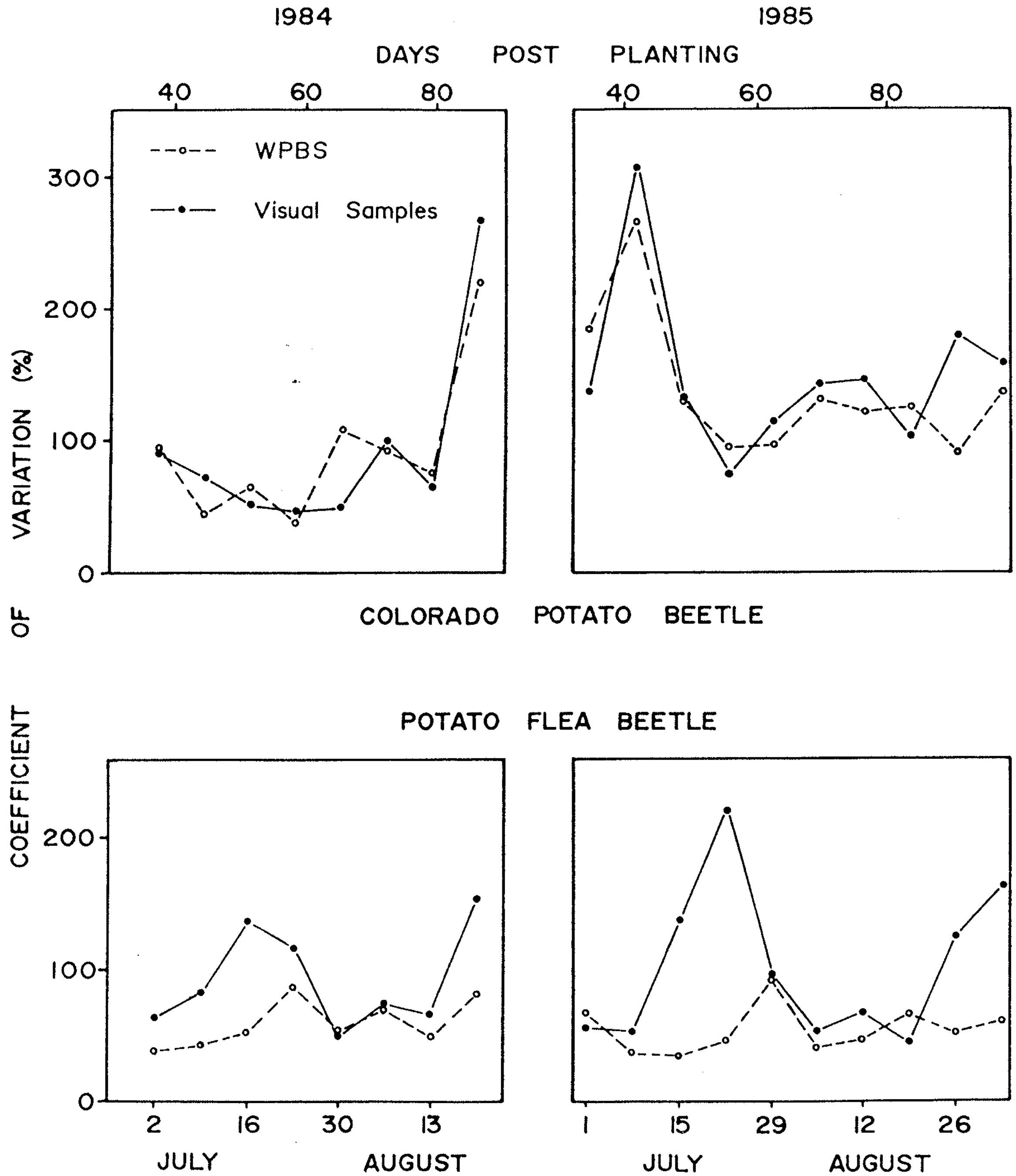

1984
1985
DAYS POST PLANTING
40
60
80
WPBS
Visual Samples
300
200
100
0
COEFFICIENT OF VARIATION (%)
COLORADO POTATO BEETLE
POTATO FLEA BEETLE
2
16
30
13
JULY
AUGUST
1
15
29
12
26

Figure 2. Number of insects estimated by visual (numbers per plant) or sweep-net (number per 25 sweeps) sampling as a function of estimate from WPBS (numbers per plant) with 95% confidence limits for the estimates of Y.

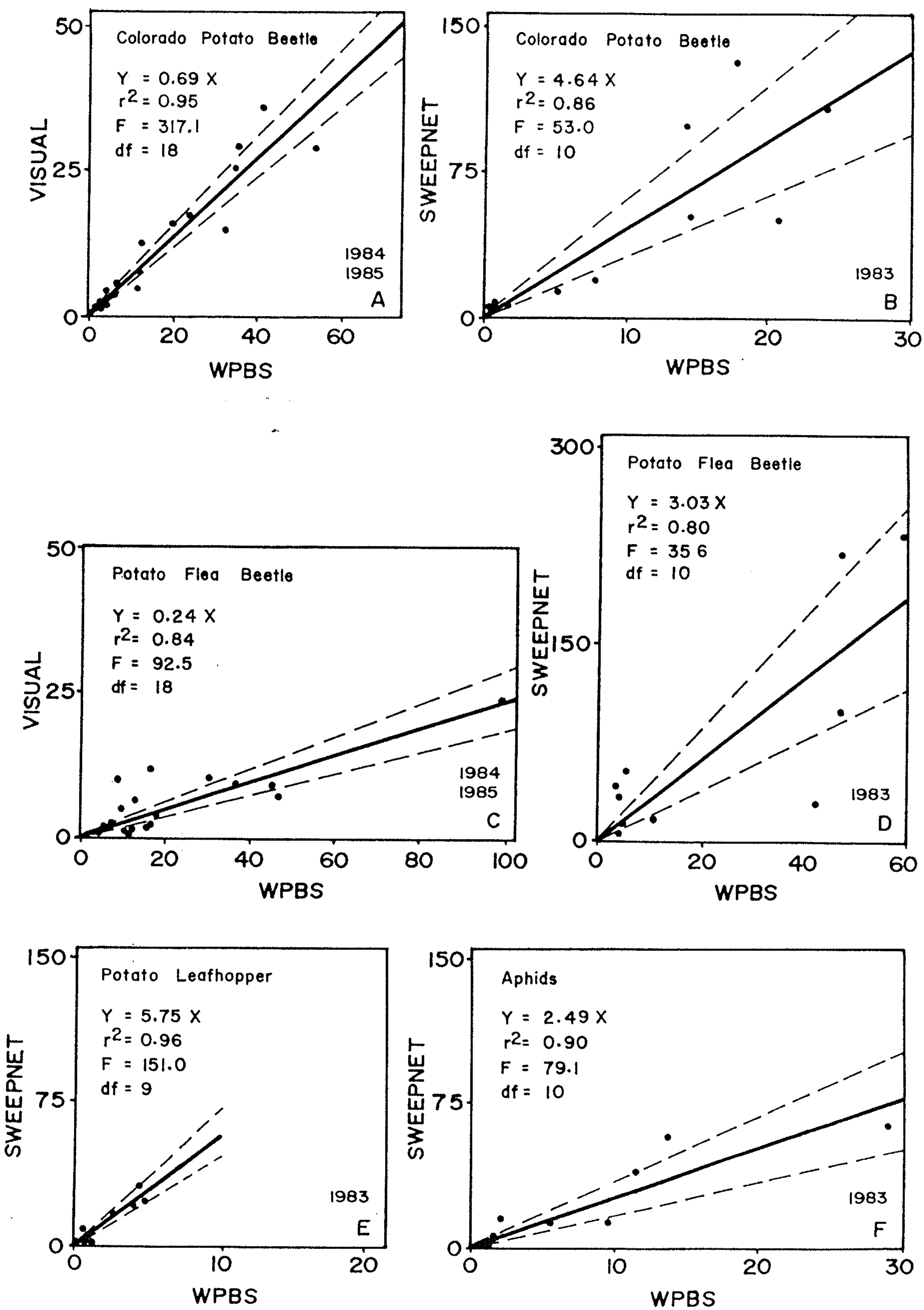
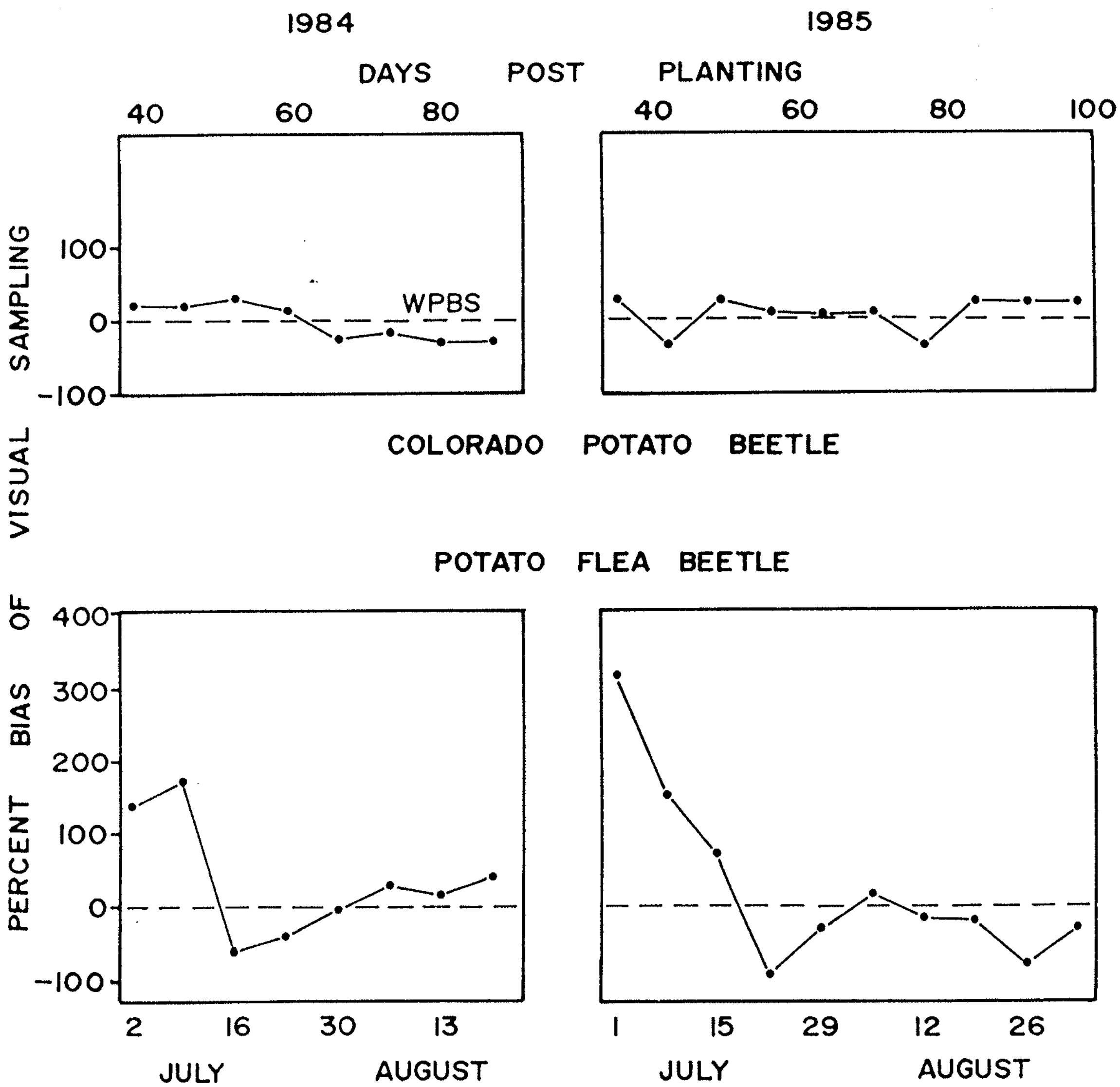
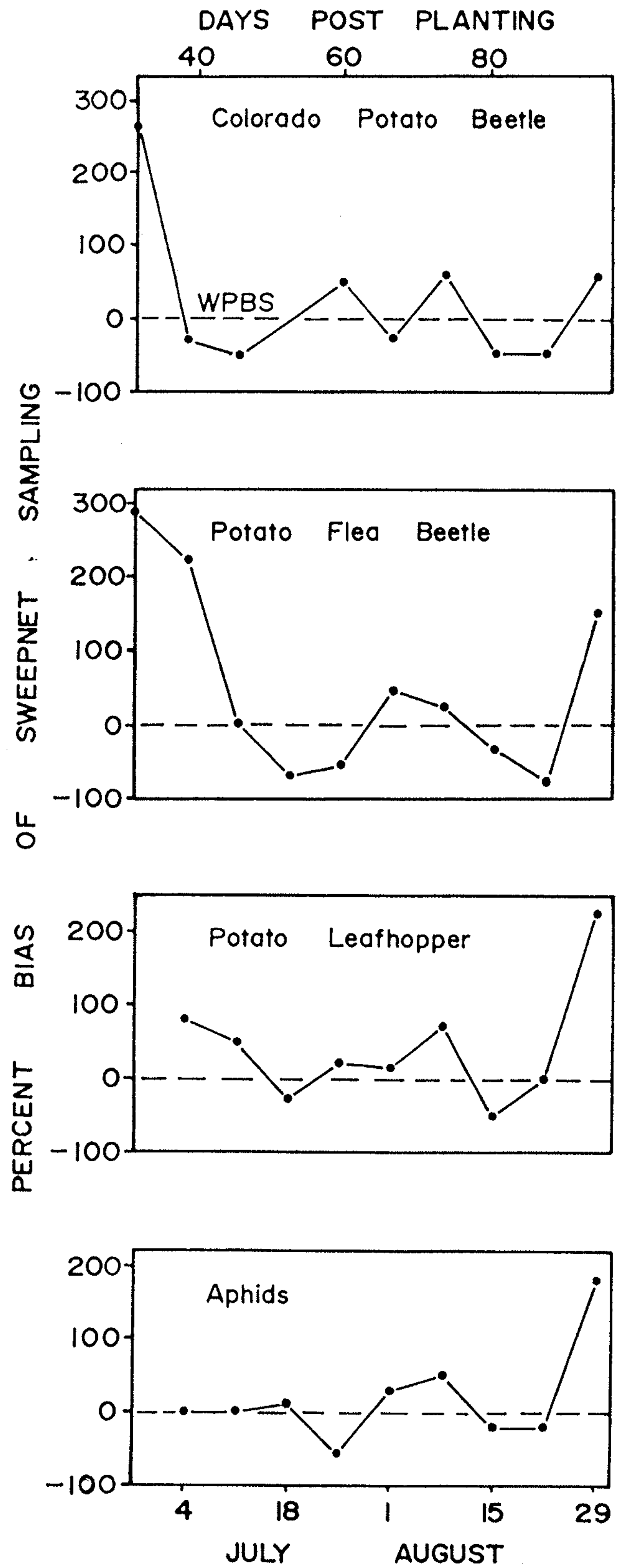

Colorado Potato Beetle
Y = 0.69 X
r2 = 0.95
F = 317.1
df = 18
1984
1985
A
VISUAL
WPBS
Colorado Potato Beetle
Y = 4.64 X
r2 = 0.86
F = 53.0
df = 10
1983
B
SWEEPNET
WPBS
Potato Flea Beetle
Y = 0.24 X
r2 = 0.84
F = 92.5
df = 18
1984
1985
C
VISUAL
WPBS
Potato Flea Beetle
Y = 3.03 X
r2 = 0.80
F = 35 6
df = 10
1983
D
SWEEPNET
WPBS
Potato Leafhopper
Y = 5.75 X
r2 = 0.96
F = 151.0
df = 9
1983
E
SWEEPNET
WPBS
Aphids
Y = 2.49 X
r2 = 0.90
F = 79.1
df = 10
1983
F
SWEEPNET
WPBS

Figure 3. Percent seasonal bias of estimates from visual sampling compared with whole plant bag sampling [100x((predicted WPBS/observed WPBS)-1)] 1984-1985.



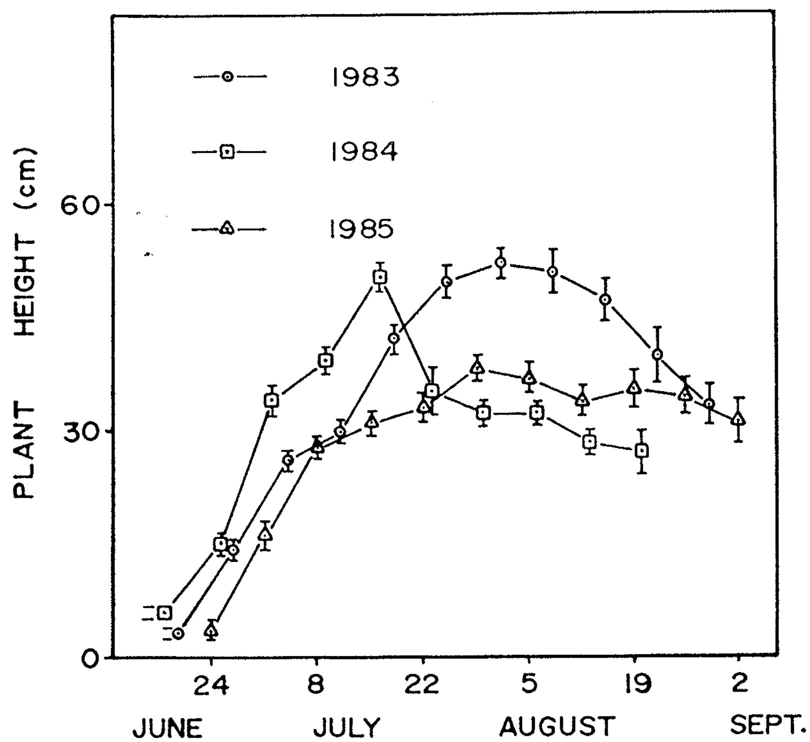
1984
1985
DAYS POST PLANTING
40
60
80
40
60
80
100
PERCENT BIAS OF VISUAL SAMPLING
100
0
-100
WPBS
COLORADO POTATO BEETLE
POTATO FLEA BEETLE
400
300
200
100
0
-100
2
16
30
13
JULY
AUGUST
1
15
29
12
26
JULY
AUGUST

Figure 4. Percent seasonal bias of estimates from sweep-net sampling compared with whole plant bag sampling [100x((predicted WPBS/observed WPBS)-1)], 1983.



DAYS POST PLANTING
40
60
80
Colorado Potato Beetle
WPBS
Potato Flea Beetle
Potato Leafhopper
Aphids
300
200
100
0
-100
PERCENT BIAS OF SWEEPNET SAMPLING
4
18
1
15
29
JULY
AUGUST

Figure 5. Plant height (mean $\pm$ S.E.) measured weekly throughout the growing season 1983-1985.


1983
1984
1985
PLANT HEIGHT (cm)
0
30
60
24
8
22
5
19
2
JUNE
JULY
AUGUST
SEPT.

Appendix 1. Insects per potato plant in soil covered and uncovered bags in whole plant bag sampling at Morden, 1985

| | July | | | | | August | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1 | 8 | 15 | 23 | 29 | 5 | 12 | 19 | 26 | 2 |
| | **Colorado potato beetle** | | | | | | | | | |
| Covered[a] | 0.4±0.4 | 2.0±1.6 | 15.0±8.2 | 16.0±5.4 | 9.0±3.2 | 5.6±3.4 | 5.6±2.8 | 3.2±1.1 | 1.2±0.6 | 0.8±0.6 |
| Uncovered[b] | 0.6±0.3 | 1.9±1.9 | 10.6±4.7 | 27.1±8.1 | 5.1±1.7 | 3.1±1.1 | 2.4±0.9 | 4.3±1.9 | 1.5±0.4 | 1.0±0.4 |
| | **Potato flea beetle** | | | | | | | | | |
| Covered | 8.8±0.8 | 16.0±2.7 | 9.2±2.2 | 12.2±2.3 | 4.6±1.7 | 30.6±4.1 | 30.0±5.0 | 92.8±26.5 | 18.4±4.5 | 4.4±1.8 |
| Uncovered | 8.0±1.8 | 16.0±1.9 | 10.2±0.9 | 10.6±1.6 | 5.8±1.8 | 29.6±4.2 | 39.5±5.9 | 102.1±22.2 | 13.9±2.1 | 5.2±0.8 |
| | **Potato leafhopper** | | | | | | | | | |
| Covered | 0 | 1.0±0.6 | 0.6±0.4 | 1.2±0.4 | 2.6±1.2 | 2.0±0.7 | 2.4±1.0 | 9.4±2.3 | 1.6±0.5 | 0 |
| Uncovered | 0 | 0.8±0.3 | 1.0±0.4 | 0.9±0.4 | 2.0±0.7 | 3.3±0.9 | 3.7±1.1 | 9.8±2.0 | 1.0±0.4 | 0 |
| | **Aphids** | | | | | | | | | |
| Covered | 0 | 0.6±0.6 | 4.4±1.6 | 7.8±2.8 | 24.8±3.1 | 48.8±10.2 | 26.6±7.2 | 28.2±7.0 | 1.8±0.8 | 0 |
| Not covered | 0 | 1.7±0.5 | 2.8±0.7 | 3.1±1.0 | 35.5±5.8 | 63.7±9.8 | 33.5±6.3 | 29.5±4.4 | 2.3±0.8 | 0 |

[a] N = 5, Mean ±S.E.

[b] N = 10, Mean ±S.E.

Appendix 2. Visual sampling[a] of Colorado potato beetle populations at Morden, 1984-1985

| | June | | July | | | | | August | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 1 |
| | | | | | | | 1984 | | | | | |
| Centre section | | | | | | | | | | | | |
| Larvae per plant | 0 | 0 | 15.1±3.8 | 28.9±5.3 | 35.9±4.8 | 25.2±3.1 | 5.2±1.2 | 0 | 0 | 0 | 0 | - |
| Adults per plant | 0.1±0.1 | 0.7±0.3 | 0.7±0.3 | 0.3±0.2 | 0.1±0.1 | 0.3±0.2 | 9.7±1.5 | 29.0±7.7 | 4.6±0.8 | 0 | 0 | - |
| Outer section | | | | | | | | | | | | |
| Larvae per plant | 0 | 0 | 27.1±4.4 | 30.0±3.6 | 36.5±5.5 | 8.5±2.1 | 1.6±0.6 | 0 | 0 | 0 | 0 | - |
| Adults per plant | 0.8±0.3 | 1.3±0.4 | 0.5±0.2 | 0.2±0.2 | 0 | 0.4±0.2 | 8.5±1.7 | 6.3±1.1 | 2.7±0.7 | 0 | 0 | - |
| | | | | | | | 1985 | | | | | |
| Centre section | | | | | | | | | | | | |
| Larvae per plant | - | 0 | 0 | 0.7±0.7 | 12.1±4.3 | 17.3±3.4 | 5.1±1.5 | 2.7±1.1 | 0.2±0.2 | 1.0±0.6 | 0 | 0 |
| Adults per plant | - | 0.1±0.1 | 0.6±0.2 | 0.3±0.2 | 0.3±0.2 | 0 | 0 | 0.2±0.1 | 1.5±0.6 | 2.9±0.8 | 1.1±0.5 | 1.0±0.4 |
| Outer section | | | | | | | | | | | | |
| Larvae per plant | - | 0 | 0 | 3.3±2.5 | 9.2±3.2 | 17.7±3.4 | 3.0±1.0 | 2.4±1.1 | 0.3±0.2 | 0.8±0.3 | 0 | 0 |
| Adults per plant | - | 0.3±0.2 | 0.9±0.3 | 0.3±0.2 | 0.1±0.1 | 0 | 0 | 1.3±0.1 | 2.3±0.9 | 5.3±1.6 | 3.0±1.0 | 1.3±0.4 |

[a] N = 15, Mean ±S.E.

Appendix 3. Visual sampling[a] of potato flea beetle populations at Morden, 1984-1985

| | June | | July | | | | | August | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Week | 3 | 4 | 1 | 2 | 3 | 4 | 5 | 1 | 2 | 3 | 4 | 1 |
| | | | | | | | 1984 | | | | | |
| Centre section | | | | | | | | | | | | |
| Adults per plant | 0.13±0.1 | 1.3±0.3 | 6.1±1.0 | 4.6±1.0 | 1.3±0.4 | 1.9±0.6 | 8.9±1.2 | 6.8±1.3 | 4.0±0.7 | 1.8±0.7 | 0 | - |
| Outer section | | | | | | | | | | | | |
| Adults per plant | 0.5±0.3 | 2.7±0.6 | 7.8±1.4 | 5.1±1.0 | 0.5±0.3 | 0.9±0.3 | 6.2±1.8 | 2.0±0.5 | 0.9±0.3 | 0.9±0.5 | 0 | - |
| | | | | | | | 1985 | | | | | |
| Centre section | | | | | | | | | | | | |
| Adults per plant | - | 2.0±0.5 | 9.7±1.4 | 11.5±1.6 | 0.9±0.3 | 0.3±0.2 | 1.5±0.4 | 10.0±1.4 | 9.1±1.6 | 23.7±2.8 | 1.4±0.5 | 1.1±0.5 |
| Outer section | | | | | | | | | | | | |
| Adults per plant | - | 3.5±0.7 | 11.1±1.7 | 12.3±1.5 | 1.5±0.4 | 0.4±0.2 | 1.7±0.6 | 10.3±1.3 | 8.7±1.7 | 29.9±3.8 | 5.8±1.4 | 1.3±0.4 |

[a] N = 15, Mean ±S.E.

# CHAPTER III

## PART II

Seasonal abundance of foliage-dwelling insect pests of potato in Manitoba

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## ABSTRACT

Patterns of seasonal abundance of Colorado potato beetle, _Leptinotarsa decemlineata_ (Say), potato flea beetle, _Epitrix cucumeris_ (Harris), potato leafhopper, _Empoasca fabae_ (Harris), and aphids on potato cv. Norland were observed in the 1983-1985 growing seasons. Estimates of populations in an experimental plot where no insecticides were applied showed that Colorado potato beetle was the most destructive species: high densities in July and August in 1983 and 1984 resulted in complete defoliation of plants. This absence of late season foliage affected population patterns and densities of other insects. In the experimental plot in 1985, adequate food attributed to low densities of Colorado potato beetle, and early senescence of leaves resulted in large populations of potato flea beetles and aphids. In growers' fields, insecticide applications for Colorado potato beetle control succeeded in maintaining very low populations of this species throughout the growing season but had very little direct effect on other potential insect pests.

# INTRODUCTION

Injury to the aerial portions of potato plants may be caused by many insect species (Radcliffe 1982). In Manitoba, the most important are the defoliators Colorado potato beetle, Leptinotarsa decemlineata (Say), potato flea beetle, Epitrix cucumeris (Harris), and the sap feeders potato leafhopper, Empoasca fabae (Harris) and aphids (Cole 1951). These species may colonize and become abundant at different stages of host development depending on planting date, cultivar susceptibility, cultural practices and prevailing weather conditions in the region. Adding to this complexity is the potato growers' frequent application of insecticides with little knowledge of their effect on target and non-target insects (Gauthier et al. 1981).

Several studies have been done on the seasonal abundance of Colorado potato beetle (Hare 1980; Ferro et al. 1983), potato flea beetle (Hanson 1933; Cannon 1949), potato leafhopper (Cancelado and Radcliffe 1979a; Walgenbach and Wyman 1984) and aphids (Wightman and Gibson 1972; Cancelado and Radcliffe 1979b; Jansson and Smilowitz 1985a, b). These studies have been conducted in areas with a longer growing season than that of Manitoba, and did not record the interactions among pest species.

The present study was conducted on the early maturing potato cultivar Norland in Manitoba where the frost free season is only 100 to 120 days (Dunlop and Shaykewich 1982). The objectives of the study were 1) to determine the seasonal abundance of foliage-dwelling insect pests in the absence of insecticides and 2) to determine the effect of insecticides on seasonal abundance.

# MATERIALS AND METHODS

Whole plant bag sampling (WPBS), visual sampling and sweep-net sampling were used to assess the density of foliage-dwelling insect species in an experimental (insecticide free) plot of cv. Norland potatoes at Morden, Manitoba in 1983-1985. The plot consisted of 50 rows 1m apart and 30m long. Fertilizer 23:23:0 231 kg per ha in 1983 and 1984, and anhydrous ammonia 84 kg per ha and 11:51:0 70 kg per ha in 1985, was broadcast and incorporated before 40-50g seed pieces were planted in late May. Weeds were controlled with EPTC and metribuzin before planting, and by hand hoeing. The plot received no insecticides during the season. Applications of captafol or dithane M-45 minimized foliar fungal diseases. In WPBS randomly selected plants were rapidly enclosed in cloth bags and removed to the laboratory for insect counting. In visual sampling the entire plant was searched for insects. In sweep-netting 25 complete (double) sweeps were made across the tops of the plants. Full details of the plot and sampling methods are given in Senanayake (1986).

In 1984 and 1985, densities of insects in the root zone were determined by taking a 10 cm diameter soil core to a depth of 15 cm immediately following removal of the aerial part of the plant by WPBS. Each core was transferred to a plastic bag and the Colorado potato beetle pupae, and potato flea beetle larvae and pupae were counted in the laboratory.

Estimates of insect densities were also made in two nearby growers fields of cv. Norland with plants of the same growth stage as those in the experimental plot. In each field a plot of 100 rows, each row 50m long, was marked along the field margin. These plots were sampled weekly, throughout the season. Sweep-net sampling for all species was done in all three years. Additionally in 1985, visual estimates were made of Colorado potato beetles and potato flea beetles on 15 randomly selected plants. Colorado potato beetle larvae were classified as early larvae (first and second instars) or late larvae (third and fourth instars).

Phenology of potato plants was recorded in the experimental plot and in the growers' fields. In all years, during the blooming period, fifteen plants were randomly selected and the plants with flower buds and open flowers were counted. At the time of harvest, levels of defoliation and the number of plants with 5% or more senesced leaves were recorded. The levels of defoliation were determined by a visual rating with a scale of 0 (no defoliation), 25, 50, 75 or 100% (complete defoliation).

Additionally in growers' fields in 1985, a total of 15 randomly selected plants were dug each week from the two fields. The height of each plant from top of the hill to the highest growing point was measured in the field and the number of leaves, leaflets (10 $cm^2$ or more) and tubers, and the yield were determined in the laboratory.

Insecticide spray records from growers' fields, and weather records (Environment Canada 1983, 1984 and 1985) were obtained for the period of the study.

# RESULTS AND DISCUSSION

Plant phenology in the experimental plot (Table 1) was similar to that in the growers' fields. Although plants in the experimental plot were completely defoliated in August 1983 and 1984, in growers' fields there was no detectable defoliation at this stage. Fig. 1 and Appendix 1 show the seasonal development of plants in growers' fields. Tuber initiation and tuber bulking were defined as swelling of stolen tips, and the rapid increase in weight respectively (Gutter 1978). Tuber bulking began following the first bloom and continued until early September.

Total rainfall and mean monthly temperatures for each growing season are shown in Table 2. The 1983 and 1984 seasons were relatively warm with low rainfall, but the 1985 season was cold and wet, particularly in August.

## Colorado potato beetle

Seasonal abundance of Colorado potato beetle in the experimental plot is shown in Fig. 2 and Appendix 2. Relatively small numbers of overwintered beetles were first observed in early summer. Larval abundance peaked 51-56 dpp (days post planting), which coincided with the first bloom stage. Adults peaked 72-84 dpp. These results are similar to those reported in the field studies of Ferro et al. (1983) in Massachusetts. In Manitoba, there is only one complete generation per year, whereas in regions with longer growing seasons beetles can complete 2-3 generations per year (Hare 1980; Wright 1984).

Population patterns were not the same in all growing seasons (Fig. 2). The ratio of densities at the adult and larval peaks in 1983 (0.71) and 1984 (1.29) greatly exceeded the ratio in 1985 (0.15). However, the ratio of densities at the pupal and larval peaks in 1984 (0.11) and 1985 (0.09) were not very different. Thus it appears that there was a higher loss of individuals from the population either in the late pupal or early adult stage in 1985. This may be attributable to the cold wet conditions of 1985 which were unlike the warm dryer conditions of the previous two growing seasons. Whether the loss of individuals in 1985 was due to the direct effect of the physical conditions or to indirect effects such as phenological differences in the plant or fungal pathogens is not clear. A decline in the population following the peak of adults could be a result of complete defoliation of plants in 1983 and 1984, and plant senescence in 1985. The adults might have dispersed into nearby growers' fields or entered overwintering sites.

In growers' fields, deltamethrin (7.5g A.I. per ha) applied at the peak of larval density resulted in a very low population throughout the 1983 growing season (Fig. 3). In 1984, application of carbofuran (360g A.I. per ha) in early July, before the larval peak gave poor control of Colorado potato beetles and an application of endosulfan (652g A.I. per ha) was made in late July. In 1985, application of carbofuran (360g A.I. per ha) in early July controlled Colorado potato beetles in the growers' fields (Fig. 4). However an application of chlorpyrifos (500g A.I. per ha) was made in late July. Comparison of the 3 year results show that a single insecticide application at the peak of larval density is sufficient to control Colorado potato beetle, whereas an early insecticide application before the peak would require another towards the middle of the season.

Potato flea beetle

The population pattern of potato flea beetle in the experimental plot is shown in Fig 5 and Appendix 3. The greatest increase in adult population was observed from mid-July to mid-August. The relatively low peak in August 1983 and 1984 compared with 1985, could be because Colorado potato beetles made plants unsuitable for potato flea beetles by completely defoliating them. In 1985, summer adults of potato flea beetle that emerged throughout August might have remained within the plot because there was adequate food for them. The population decline in late August could have been the result of plant senescence. A similar trend in population pattern of this species was observed on the early maturing potato cultivar Early Rose in Washington (Hanson 1933).

The growers' insecticide application in early July had very little impact on the species (Fig. 6 and 7). This could be because the insecticides were applied at a time when the overwintered potato flea beetles were dying and the summer generation was still in the soil. The second insecticide application in late-July in 1984 and 1985 was not effective in maintaining a very low population of potato flea beetles for the remainder of the season. Therefore, the growers' insecticide applications to control Colorado potato beetles did not provide season-long control of potato flea beetles.

Potato leafhopper

The seasonal abundance of potato leafhopper is shown in Fig. 8 and Appendix 4. Small numbers of overwintered insects were observed in early July. A gradual increase of density of the summer population occurred in July and August, and populations peaked in early-July and again in early- or mid-August. The early decline in population in 1983 and 1984 could be due to complete defoliation of plants attributed to Colorado potato beetle feeding. A similar pattern was observed with potato leafhoppers in Minnesota with peaks in mid-July and mid-August (Cancelado and Radcliffe 1979a; Johnston 1981).

The effect of growers' insecticide applications on seasonal abundance of potato leafhopper is shown in Fig. 9. The insecticide applications in July 1983 to control Colorado potato beetles did not appear to affect population density of potato leafhoppers.

Aphids

Aphids were identified as the green peach aphid, Myzus persicae (Sulzer), and the potato aphid, Macrosiphum euphorbiae (Thomas) (Senanayake 1986). During regular sampling, aphids were not identified beyond the familial level. Aphids were first observed in early July in the experimental plot (Fig. 10; Appendix 5). Populations peaked in early- or mid-August and this is similar to the pattern observed in Minnesota (Cancelado and Radcliffe 1979b; Johnston 1981). In 1985, large numbers of aphids were observed in early August. This could be attributed to the effects of the weather on parasitoids and predators or to the senescence of plants early in the season. Such an early senescence was not observed in the previous years. Many workers have reported greater abundance and reproductive rates of aphids on senescing potato leaves than on those which are not senescing or are actively growing (Bradley 1952; Shands et al. 1954; Jansson and Smilowitz 1985a, b). The low densities in 1983 and 1984 could be due to complete defoliation of plants in August.

Population patterns in the growers' fields showed no evidence that the insecticides controlled aphid populations (Fig. 11). This may be due to lack of synchrony between insecticide applications for Colorado potato beetle control and the period of increase for aphid populations.

# CONCLUSIONS

In Manitoba, Colorado potato beetle was the most destructive insect on potatoes. In warm, dry seasons uncontrolled populations of this species completely defoliated and killed the plants by early- or mid-August at the time when rapid tuber bulking normally would have occurred. This absence of foliage late in the season resulted in low densities or early decline of other potential insect pests. In contrast adequate supplies of food associated with low densities of Colorado potato beetle in 1985 resulted in higher densities of potato flea beetles and aphids.

Growers' insecticide applications were successful in controlling Colorado potato beetle populations which is their main concern. However, these applications did not give effective control of potato flea beetles, potato leafhoppers and aphids found in the same locality but rather preserved the plants so that these later pests were able to attack them. The study shows that early herbivory by Colorado potato beetle negatively affects the population densities of late feeding insect pests on potatoes, and therefore is important in structuring this phytophagous insect community.

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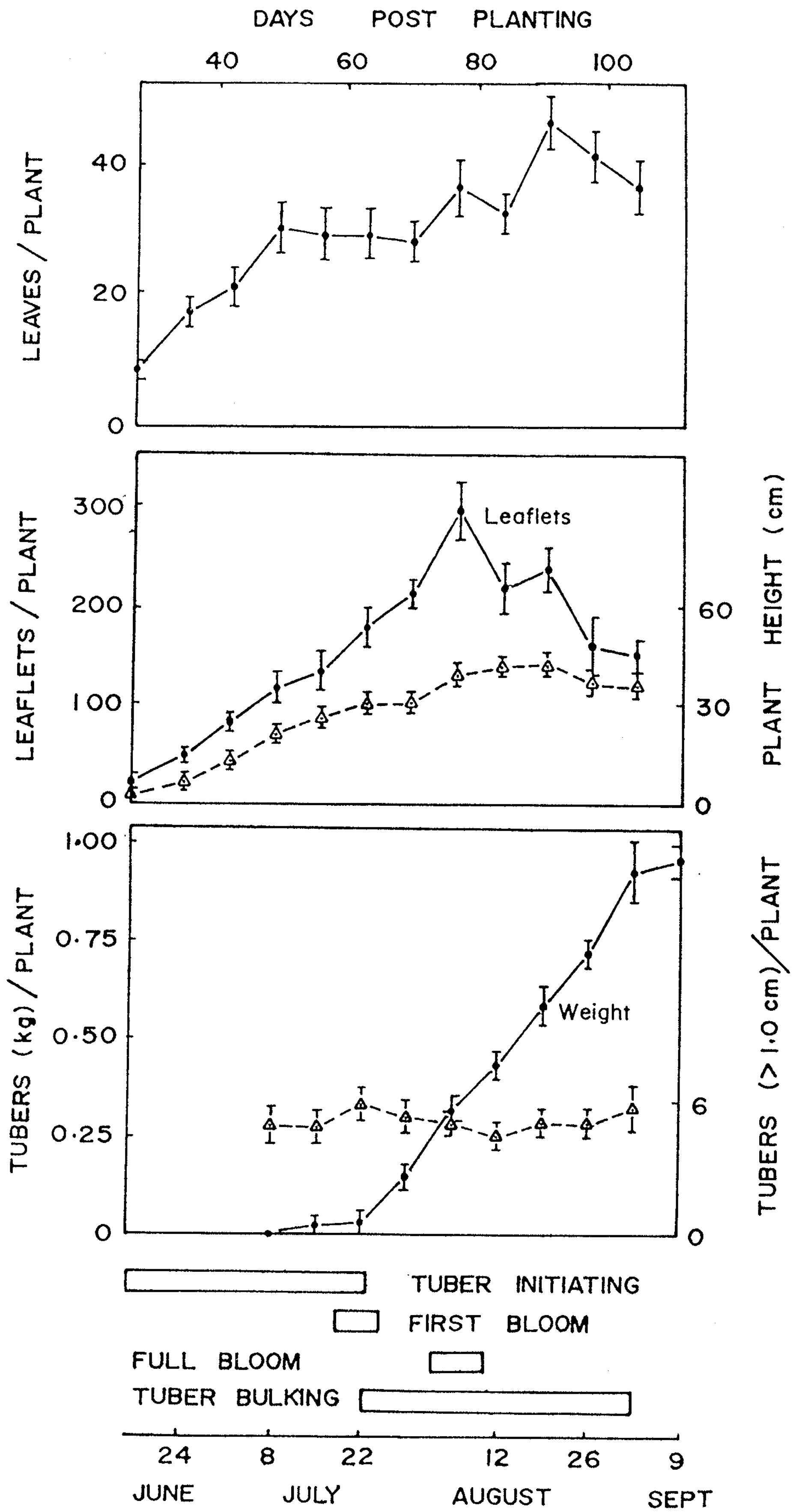
Table 1. Dates of seeding, harvest and plant phenology in the experimental plot at Morden, 1983-1985

| | Seeding | Emergence | First bloom | Full bloom | Complete defoliation | Harvest | Defoliation per plant(%) | Senescenced plants (%) |
|---|---|---|---|---|---|---|---|---|
| 1983 | 26 May | 20 June | 18 July | 8 August | 29 August | 12 September | 100 | 0 |
| 1984 | 25 May | 18 June | 16 July | 6 August | 13 August | 8 September | 100 | 0 |
| 1985 | 27 May | 24 June | 22 July | 5 August | Not observed | 9 September | 25-75 | 100 |

Table 2. Total rainfall and mean monthly temperatures for the months of June-August at Morden, 1983-1985

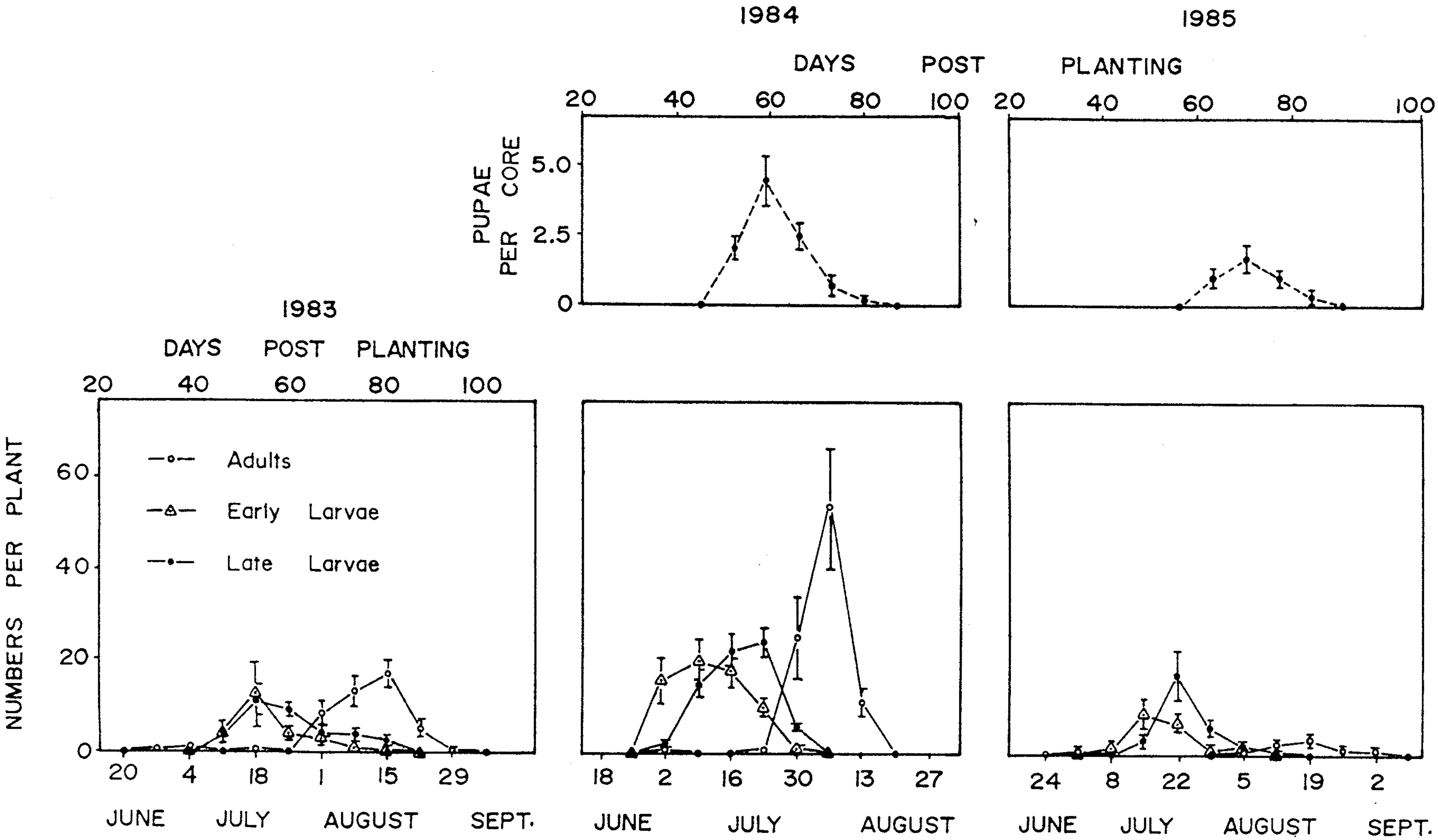
| | 1983 | | | 1984 | | | 1985 | | |
|---|---|---|---|---|---|---|---|---|---|
| | June | July | August | June | July | August | June | July | August |
| Rainfall mm | 61 | 37 | 59 | 120 | 38 | 26 | 116 | 41 | 194 |
| Mean air temperature °C | 18 | 23 | 23 | 18 | 21 | 22 | 15 | 19 | 16 |
| Mean soil (10 cm) temperature °C | 17 | 21 | 23 | 16 | 19 | 20 | 12 | 18 | 14 |

Figure 1. Growth characteristics (mean $\pm$ S.E.) of the potato plant *Solanum tuberosum* L. (cv. Norland) in the growers' fields at Morden, 1985.



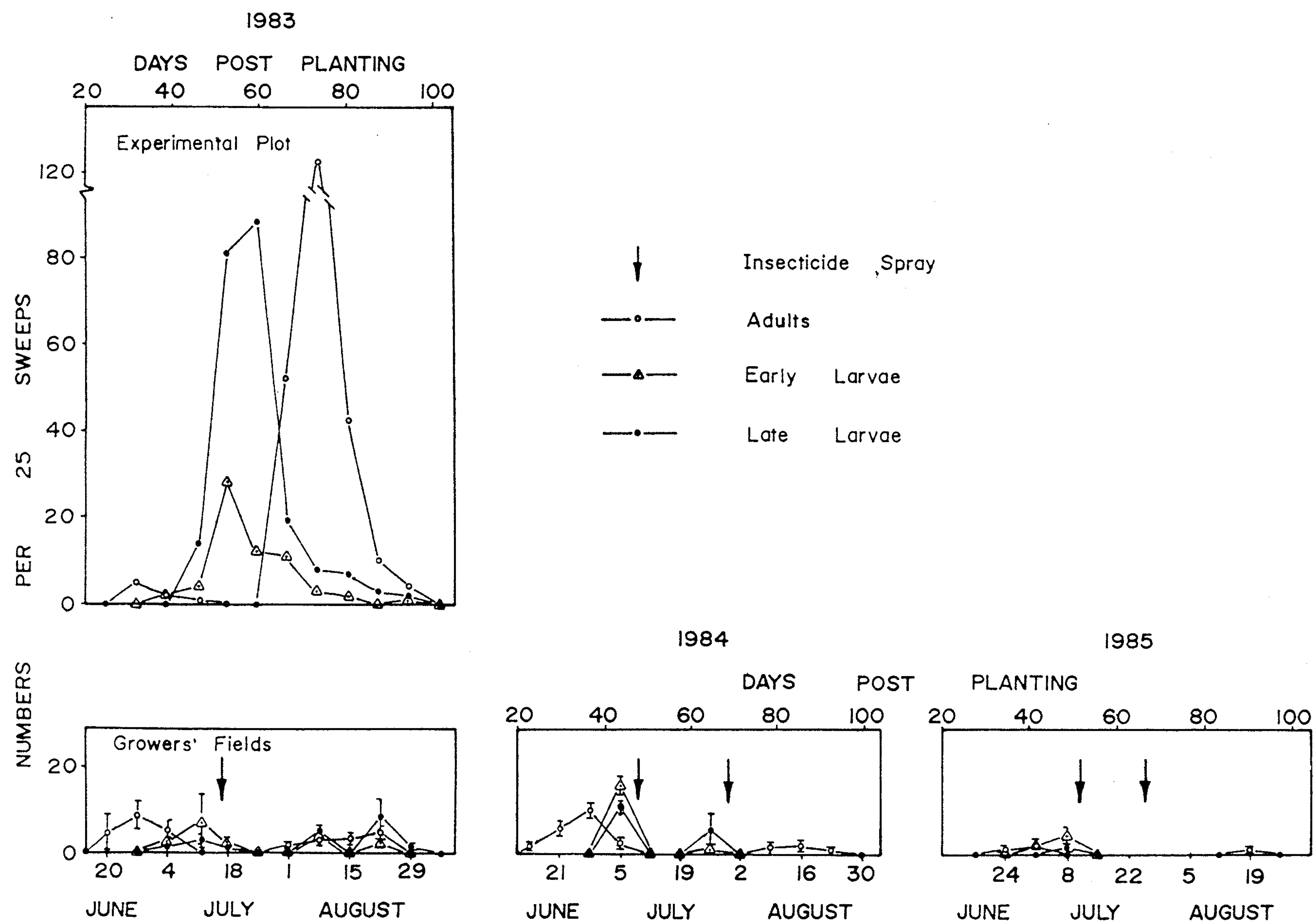
DAYS POST PLANTING
40
60
80
100
LEAVES / PLANT
40
20
0
Leaflets
LEAFLETS / PLANT
300
200
100
0
PLANT HEIGHT (cm)
60
30
0
Weight
TUBERS (kg) / PLANT
1.00
0.75
0.50
0.25
0
TUBERS (> 1.0 cm)/PLANT
6
0
TUBER INITIATING
FIRST BLOOM
FULL BLOOM
TUBER BULKING
24
8
22
12
26
9
JUNE
JULY
AUGUST
SEPT

Figure 2. Mean (± S.E.) number of Colorado potato beetle larvae or adults per whole plant bag sample and pupae per soil core taken in the experimental plot, 1983-1985.



1984
1985
DAYS POST PLANTING
20 40 60 80 100
PUPAE PER CORE
5.0
2.5
0
1983
DAYS POST PLANTING
20 40 60 80 100
NUMBERS PER PLANT
60
40
20
0
Adults
Early Larvae
Late Larvae
20 4 18 1 15 29
JUNE JULY AUGUST SEPT.
18 2 16 30 13 27
JUNE JULY AUGUST
24 8 22 5 19 2
JUNE JULY AUGUST SEPT.

Figure 3. Mean (± S.E.) number of Colorado potato beetle larvae or adults in sweep-net samples in the experimental plot, 1983 and growers' fields (insecticide applied), 1983-1985.



1983
DAYS POST PLANTING
20 40 60 80 100
Experimental Plot
120
80
60
40
20
0
NUMBERS PER 25 SWEEPS
Insecticide Spray
Adults
Early Larvae
Late Larvae
Growers' Fields
20
0
20 4 18 1 15 29
JUNE JULY AUGUST
1984
1985
DAYS POST PLANTING
20 40 60 80 100
21 5 19 2 16 30
JUNE JULY AUGUST
20 40 60 80 100
24 8 22 5 19
JUNE JULY AUGUST

Figure 4. Mean ($\pm$ S.E.) number of Colorado potato beetle larvae and adults in visual samples in the experimental plot and growers' fields (insecticide applied), 1985.

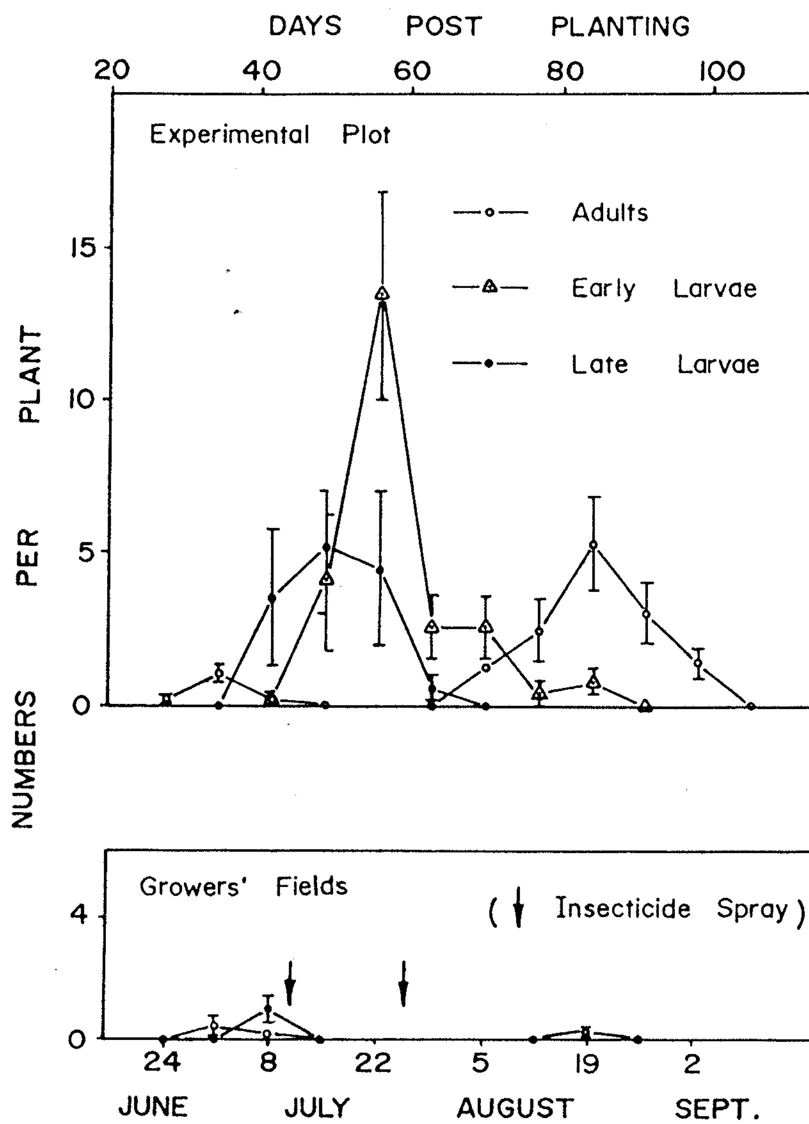

DAYS POST PLANTING
20
40
60
80
100
Experimental Plot
Adults
Early Larvae
Late Larvae
15
10
5
0
NUMBERS PER PLANT
Growers' Fields
( Insecticide Spray )
4
0
24
8
22
5
19
2
JUNE
JULY
AUGUST
SEPT.

Figure 5. Mean (± $\hat{S}$.E.) number of potato flea beetle adults per whole plant bag sample and pupae or larvae per soil core taken in the experimental plot, 1983-1985.

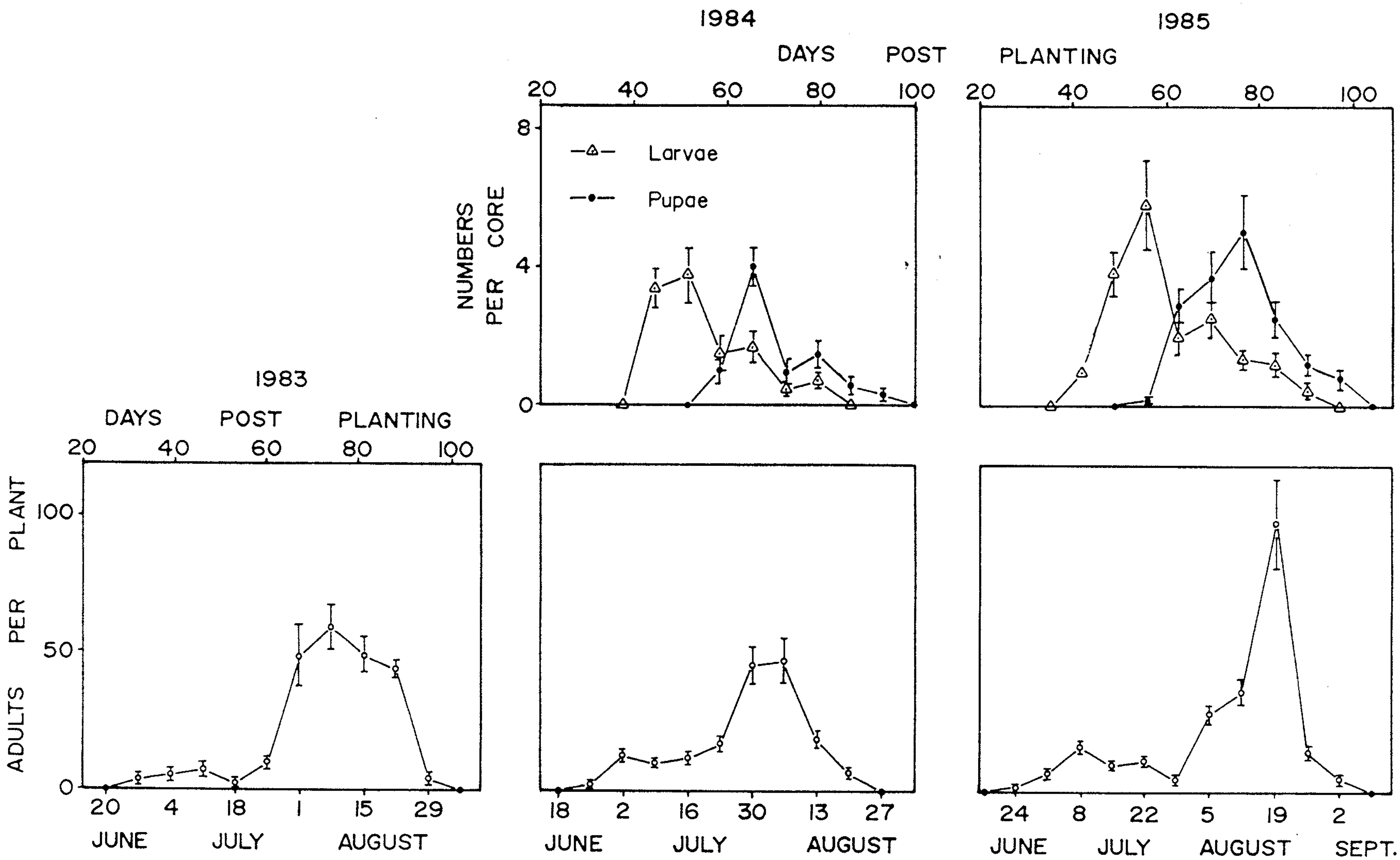

1983
DAYS POST PLANTING
20 40 60 80 100
ADULTS PER PLANT
0 50 100
20 4 18 1 15 29
JUNE JULY AUGUST
1984
1985
DAYS POST PLANTING
20 40 60 80 100
NUMBERS PER CORE
0 4 8
Larvae
Pupae
18 2 16 30 13 27
JUNE JULY AUGUST
24 8 22 5 19 2
JUNE JULY AUGUST SEPT.

Figure 6. Mean ($\pm$ S.E.) number of potato flea beetles in sweep-net samples in the experimental plot, 1983 and growers' fields (insecticide applied), 1983-1985.

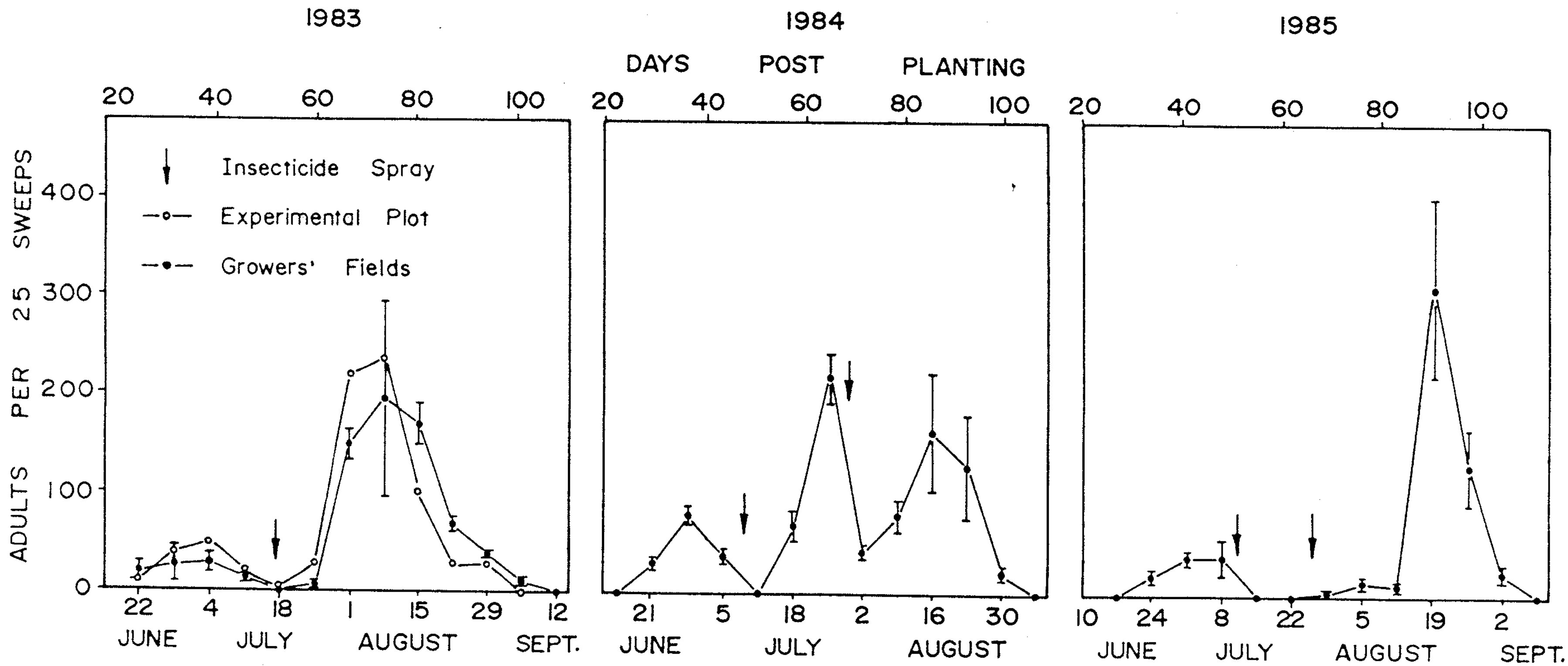
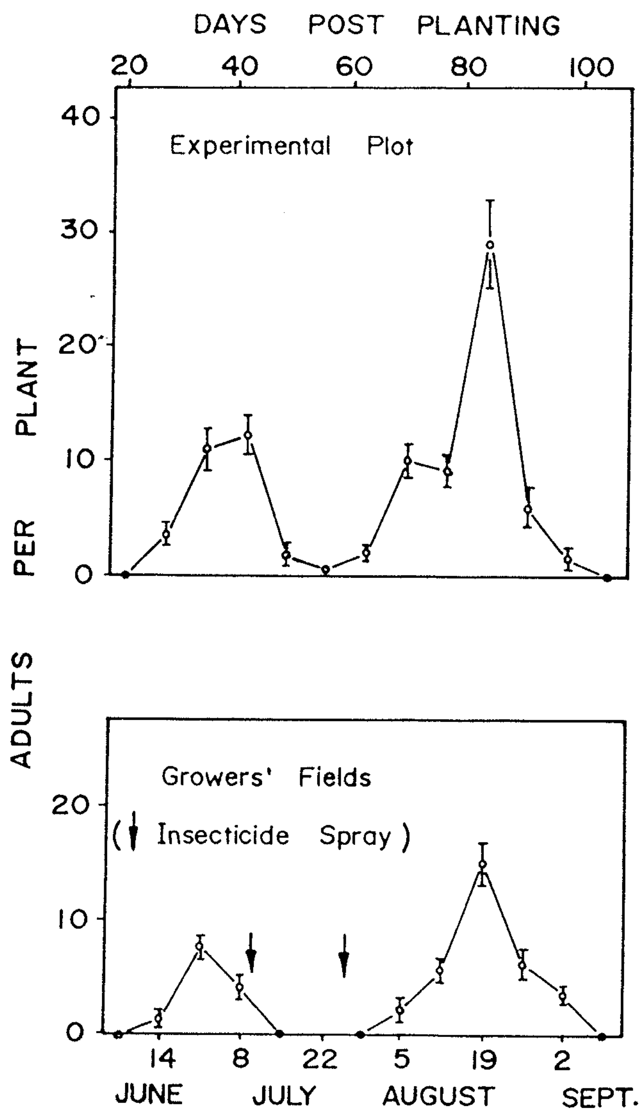

1983
1984
1985
DAYS POST PLANTING
Insecticide Spray
Experimental Plot
Growers' Fields
ADULTS PER 25 SWEEPS
JUNE
JULY
AUGUST
SEPT.

Figure 7. Mean (± S.E.) number of potato flea beetle adults in visual samples in the experimental plot and growers' fields (insecticide applied), 1985.



DAYS POST PLANTING
20
40
60
80
100
40
30
20
10
0
Experimental Plot
PER PLANT
ADULTS
Growers' Fields
( Insecticide Spray )
20
10
0
14
8
22
5
19
2
JUNE
JULY
AUGUST
SEPT.

Figure 8. Mean ($\pm$ S.E.) number of potato leafhoppers per whole plant bag sample in the experimental plot, 1983-1985.

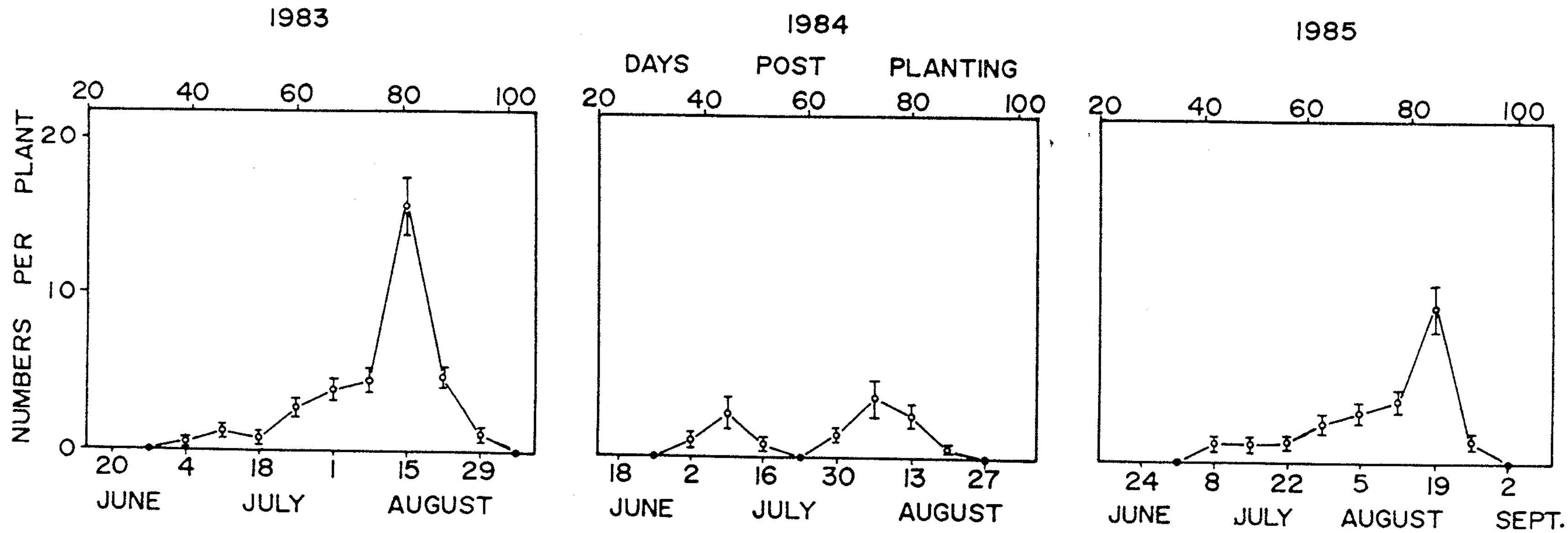

1983
1984
1985
DAYS POST PLANTING
20 40 60 80 100
NUMBERS PER PLANT
0 10 20
20 4 18 1 15 29
JUNE JULY AUGUST
18 2 16 30 13 27
JUNE JULY AUGUST
24 8 22 5 19 2
JUNE JULY AUGUST SEPT.

Figure 9. Mean (± S.E.) number of potato leafhoppers in sweep-net samples in the experimental plot, 1983 and growers' fields (insecticide applied), 1983-1985.

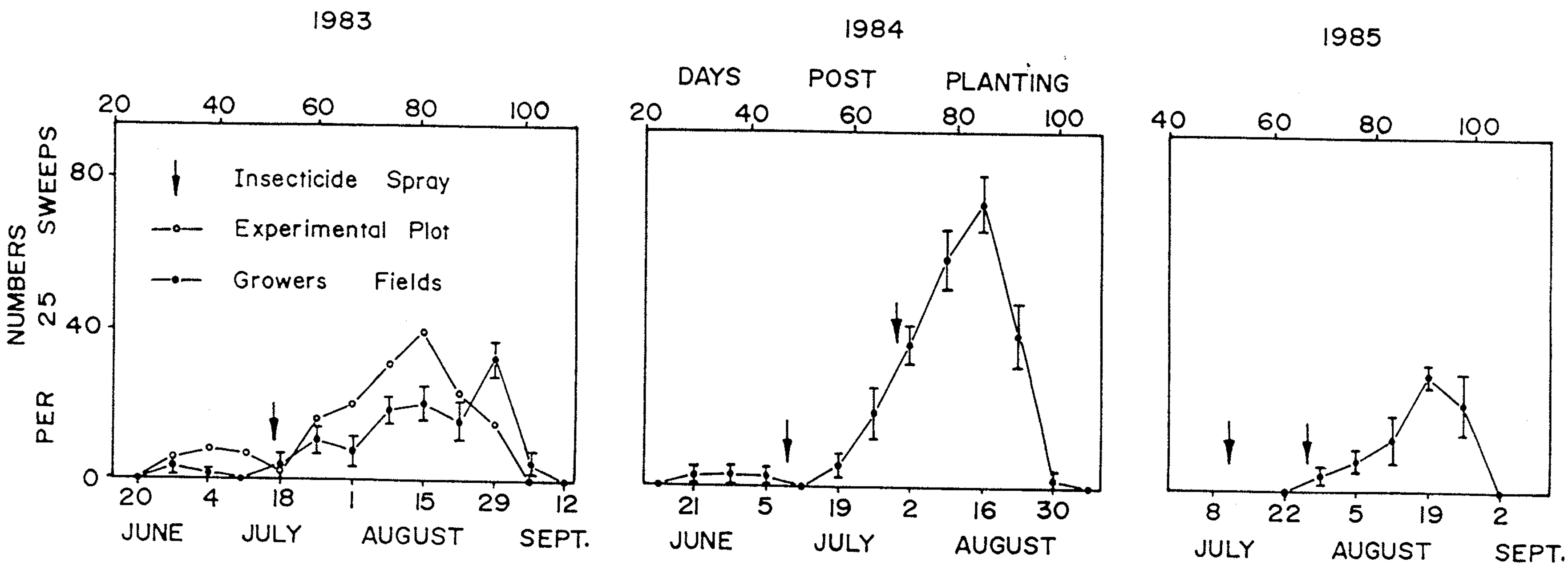

1983
1984
1985
DAYS POST PLANTING
20 40 60 80 100
40 60 80 100
NUMBERS PER 25 SWEEPS
0 40 80
Insecticide Spray
Experimental Plot
Growers Fields
20 4 18 1 15 29 12
JUNE JULY AUGUST SEPT.
21 5 19 2 16 30
JUNE JULY AUGUST
8 22 5 19 2
JULY AUGUST SEPT.

Figure 10. Mean ($\pm$ S.E.) number of aphids per whole plant bag sample taken in the experimental plot, 1983-1985.

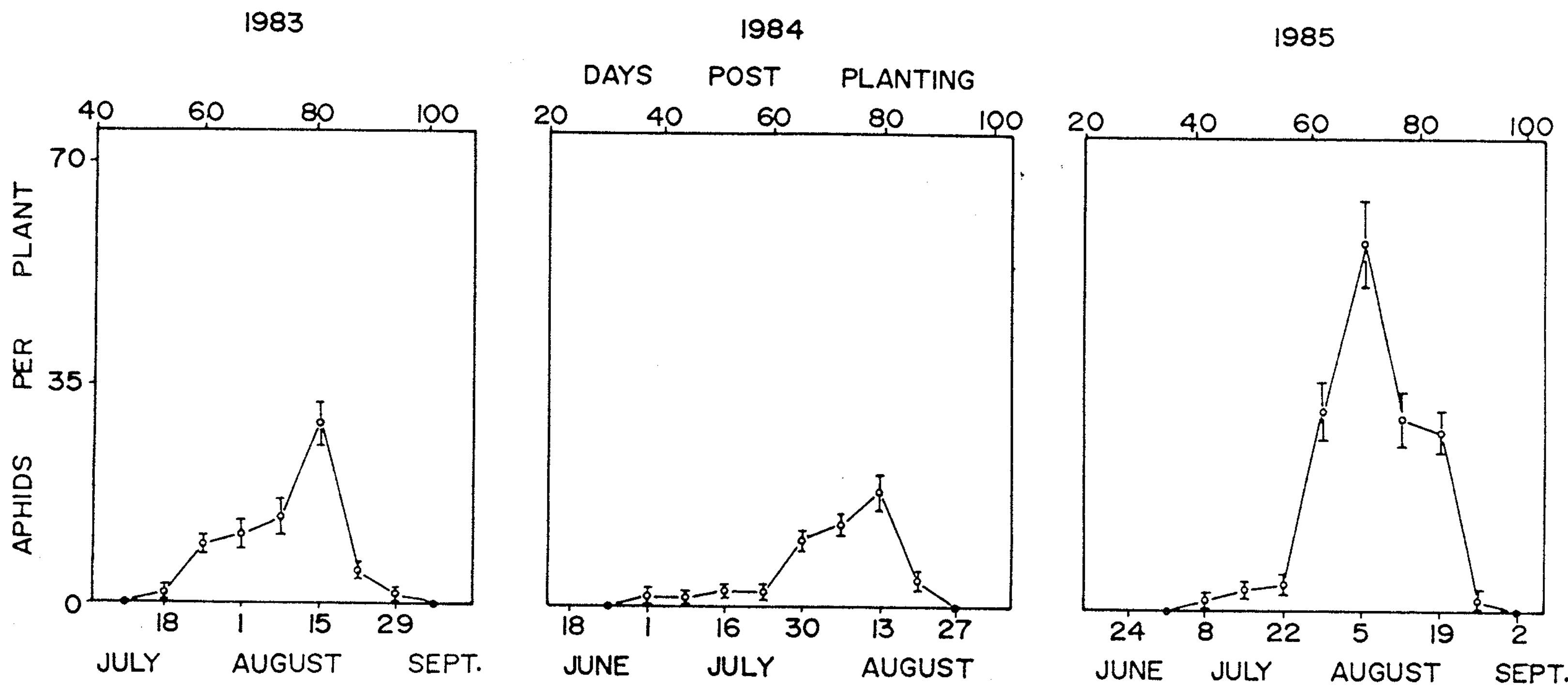
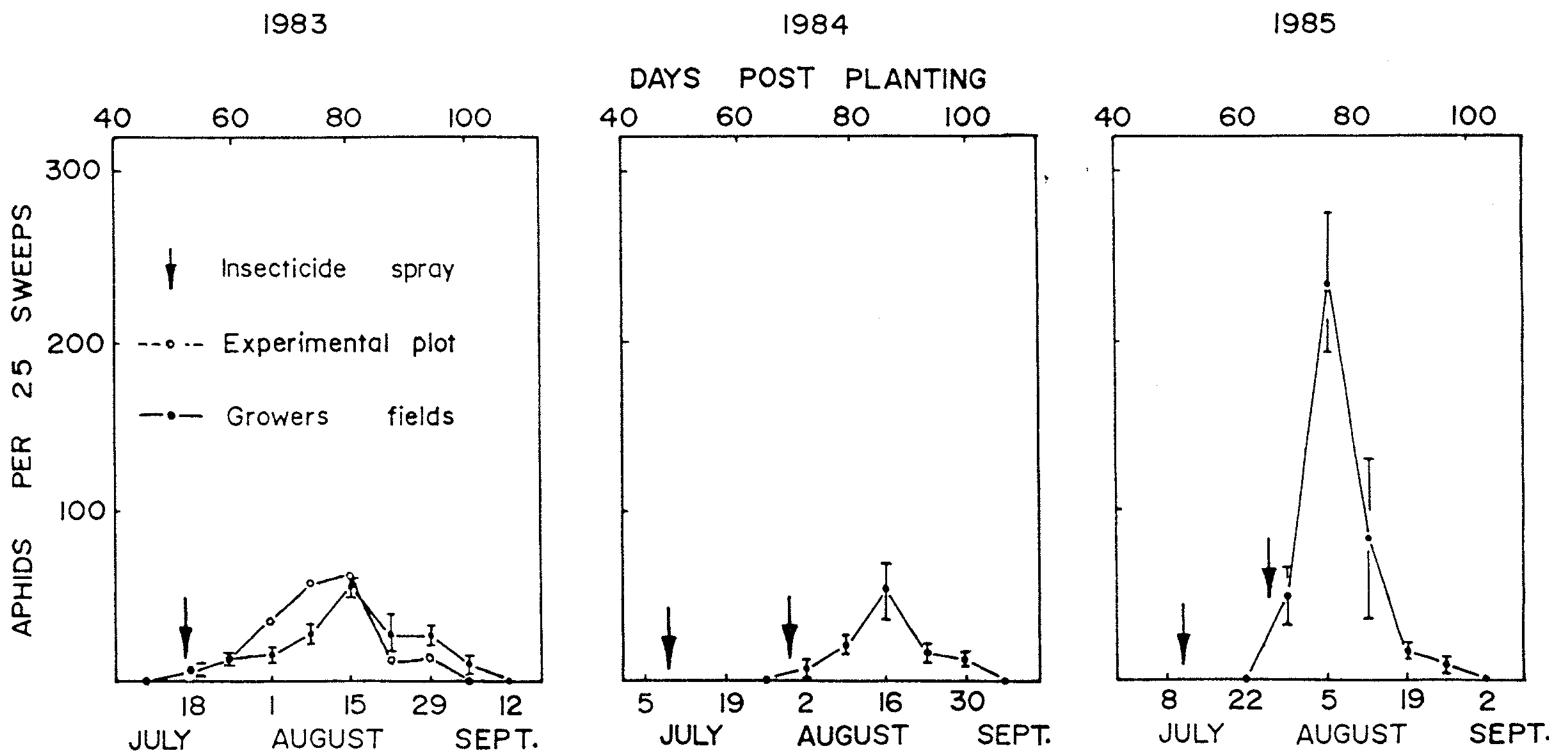

1983
1984
1985
DAYS POST PLANTING
40
60
80
100
20
40
60
80
100
20
40
60
80
100
APHIDS PER PLANT
70
35
0
18
1
15
29
JULY
AUGUST
SEPT.
18
1
16
30
13
27
JUNE
JULY
AUGUST
24
8
22
5
19
2
JUNE
JULY
AUGUST
SEPT.

Figure 11. Mean ($\pm$ S.E.) number of aphids in sweep-net samples in the experimental plot, 1983 and growers' fields (insecticide applied), 1983-1985.


1983
1984
1985
DAYS POST PLANTING
40
60
80
100
300
200
100
APHIDS PER 25 SWEEPS
Insecticide spray
Experimental plot
Growers fields
18
1
15
29
12
JULY
AUGUST
SEPT.
5
19
2
16
30
8
22
5
19
2

Appendix 1. Growth statistics of the potato plant <u>Solanum tuberosum</u> (L.) (cv. Norland) in growers' fields at Morden, 1985

| Date | Days post-planting | Mean[a] plant height (±S.E.) (cm) | Mean number of leaves (±S.E.) | Mean number of leaflets (±S.E.) | Mean number of tubers (±S.E.) (>1.0 cm dia.) | Mean weight of total yield (±S.E.) (kg) | % Plants with flower buds | % Plants with open flowers | % Plants with senescent leaves |
|---|---|---|---|---|---|---|---|---|---|
| June | | | | | | | | | |
| 17 | 28 | 3.0±0.2 | 7.5±1.0 | 16.5±2.0 | 0 | 0 | 0 | 0 | 0 |
| 24 | 35 | 5.5±0.3 | 17.1±2.0 | 48.1±6.7 | 0 | 0 | 0 | 0 | 0 |
| July | | | | | | | | | |
| 1 | 42 | 14.5±1.0 | 20.9±3.0 | 77.3±11.0 | 0 | 0 | 0 | 0 | 0 |
| 8 | 49 | 20.6±1.0 | 29.9±3.6 | 118.3±10.8 | 5.2±0.9 | 0 | 0 | 0 | 0 |
| 15 | 56 | 26.6±1.0 | 28.7±3.6 | 134.3±19.0 | 5.0±0.6 | 0.03±0.01 | 13.3±9.1 | 0 | 0 |
| 22 | 63 | 31.8±2.1 | 29.0±3.5 | 181.3±19.4 | 6.0±0.7 | 0.03±0.01 | 46.7±13.3 | 26.7±11.8 | 0 |
| 29 | 70 | 31.5±1.5 | 28.1±2.9 | 210.8±14.4 | 5.4±0.4 | 0.15±0.02 | 33.3±13.3 | 33.3±13.3 | 0 |
| Aug. | | | | | | | | | |
| 5 | 77 | 39.3±1.3 | 36.5±4.2 | 296.4±33.0 | 5.1±0.3 | 0.31±0.04 | 13.3±9.1 | 60.0±13.3 | 13.3±9.1 |
| 12 | 84 | 41.1±2.2 | 32.3±2.0 | 216.0±32.0 | 4.5±0.2 | 0.44±0.03 | 0 | 26.7±11.8 | 13.3±9.1 |
| 19 | 91 | 43.6±1.8 | 46.3±3.2 | 240.7±18.5 | 5.2±0.3 | 0.58±0.05 | 0 | 0 | 46.7±13.3 |
| 26 | 98 | 37.3±2.1 | 40.9±4.0 | 160.2±30.3 | 5.2±0.4 | 0.71±0.03 | 0 | 0 | 100.0±0.0 |
| Sept. | | | | | | | | | |
| 2 | 105 | 36.4±1.8 | 35.7±3.8 | 148.9±16.5 | 5.9±0.8 | 0.93±0.07 | 0 | 0 | 100.0±0.0 |

[a] N = 15.

Appendix 2. Whole plant bag sampling of Colorado potato beetle populations at Morden, 1983-1985

| | June | July | | | | | August | | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1983** | | | | | | | | | | | | |
| Larvae/plant[a] | 0 | 0.5±0.4 | 7.5±2.9 | 23.8±6.4 | 13.9±1.5 | | 6.9±2.1 | 4.7±1.1 | 3.8±0.6 | 0 | 0 | 0 |
| Min.-Max. | 0 | 0-5 | 0-36 | 0-90 | 6-29 | | 0-30 | 0-13 | 0-7 | 0 | 0 | 0 |
| Adults/plant | 0.3±0.1 | 0.7±0.2 | 0.2±0.2 | 0.3±0.2 | 0.2±0.1 | | 7.6±1.3 | 12.8±3.1 | 16.9±3.1 | 5.1±0.7 | 0.7±0.3 | 0 |
| Min.-Max. | 0-1 | 0-2 | 0-2 | 0-2 | 0-1 | | 3-23 | 3-46 | 1-42 | 0-11 | 0-4 | 0 |
| **1984** | | | | | | | | | | | | |
| Larvae/plant | - | 18.3±4.8 | 34.6±4.2 | 40.8±6.9 | 33.9±3.3 | 6.7±1.1 | 0.6±0.3 | 0 | 0 | 0 | | - |
| Min.-Max. | - | 0-63 | 3-54 | 3-103 | 20-62 | 0-14 | 0-3 | 0 | 0 | 0 | | - |
| Adults/plant | - | 0.9±0.3 | 0.5±0.2 | 0.1±0.1 | 0.5±0.2 | 25.1±9.1 | 52.8±12.9 | 11.1±2.2 | 0.3±0.2 | 0 | | - |
| Min.-Max. | - | 0-3 | 0-3 | 0-1 | 0-2 | 7-148 | 8-173 | 2-32 | 0-2 | 0 | | - |
| **1985** | | | | | | | | | | | | |
| Larvae/plant | - | 0 | 2.0±1.3 | 11.9±4.0 | 23.1±5.8 | 6.3±1.6 | 3.2±1.2 | 1.2±0.6 | 0.5±0.2 | 0 | | 0 |
| Min.-Max. | - | 0 | 0-18 | 0-45 | 3-71 | 0-20 | 0-15 | 0-8 | 0-3 | 0 | | 0 |
| Adults/plant | - | 0.5±1.3 | 0.2±0.1 | 0.2±0.1 | 0.1±0.1 | 0.1±0.1 | 0.7±0.4 | 2.1±0.6 | 3.4±1.2 | 1.4±0.3 | | 0.9±0.3 |
| Min.-Max. | - | 0-3 | 0-1 | 0-1 | 0-1 | 0-1 | 0-5 | 0-8 | 0-17 | 0-4 | | 0-4 |

[a] N = 15, Mean ±S.E.

Appendix 3. Whole plant bag sampling of potato flea beetle populations at Morden, 1983-1985

| | June | July | | | | | August | | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | 1983 | | | | | | |
| Adults/plant[a] | 3.2±0.8 | 5.2±0.7 | 7.1±1.9 | 3.7±0.8 | 10.5±1.1 | | 48.1±11.0 | 59.0±8.7 | 47.6±4.0 | 42.8±4.4 | 3.9±0.7 | 0 |
| Min.-Max. | 0-12 | 0-12 | 0-29 | 0-9 | 4-20 | | 9-182 | 18-157 | 27-75 | 14-63 | 0-8 | 0 |
| | | | | | | 1984 | | | | | | |
| Adults/plant | - | 12.4±1.3 | 9.3±1.0 | 11.9±1.6 | 16.3±3.7 | 45.0±6.3 | 46.5±8.2 | 18.4±2.3 | 7.3±1.6 | 0 | | - |
| Min.-Max. | - | 4-21 | 2-14 | 2-24 | 0-52 | 6-93 | 7-123 | 0-33 | 0-21 | 0 | | - |
| | | | | | | 1985 | | | | | | |
| Adults/plant | - | 8.3±1.2 | 16.0±1.5 | 9.9±0.9 | 11.1±1.3 | 5.4±1.3 | 29.9±3.2 | 36.3±4.3 | 99.0±16.7 | 15.4±2.1 | | 4.9±0.8 |
| Min.-Max. | - | 0-19 | 0-26 | 2-15 | 5-21 | 0-17 | 17-62 | 18-68 | 31-249 | 3-34 | | 1-11 |

[a] N = 15, Mean ±S.E.

Appendix 4. Whole plant bag sampling of potato leafhopper populations at Morden, 1983-1985

| | June | July | | | | | August | | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | 1983 | | | | | | | |
| Leafhoppers/plant[a] | 0 | 0.5±0.2 | 1.2±0.4 | 0.7±0.3 | 2.6±0.5 | | 3.9±0.7 | 4.4±0.7 | 15.7±1.9 | 4.7±0.7 | 1.1±0.3 | 0 |
| Min.-Max. | 0 | 0-3 | 0-5 | 0-3 | 0-8 | | 1-9 | 2-12 | 3-30 | 2-11 | 0-3 | 0 |
| | | | | | 1984 | | | | | | | |
| Leafhoppers/plant | - | 0.9±0.3 | 2.5±0.9 | 0.7±0.3 | 0 | 1.3±0.4 | 3.7±1.1 | 2.4±0.8 | 0.2±0.2 | 0 | | - |
| Min.-Max. | - | 0-4 | 0-10 | 0-3 | 0 | 0-5 | 0-13 | 0-9 | 0-2 | 0 | | - |
| | | | | | 1985 | | | | | | | |
| Leafhoppers/plant | - | 0 | 0.9±0.3 | 0.9±0.3 | 1.0±0.3 | 2.2±0.6 | 2.9±0.7 | 3.7±0.8 | 9.7±1.5 | 1.2±0.3 | | 0 |
| Min.-Max. | - | 0 | 0-3 | 0-3 | 0-3 | 0-7 | 0-8 | 0-11 | 2-19 | 0-3 | | 0 |

[a] N = 15, Mean ±S.E.

Appendix 5. Whole plant bag sampling of aphid populations at Morden, 1983-1985

| | June | July | | | | | August | | | | | Sept. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **1983** | | | | | | | | | | | | |
| Aphids/plant[a] | 0 | 0 | 0.9±0.3 | 1.7±0.6 | 9.5±1.3 | | 11.4±2.1 | 13.7±2.2 | 29.2±3.4 | 5.6±1.0 | 1.9±0.7 | 0 |
| Min.-Max. | 0 | 0 | 0-4 | 0-7 | 2-17 | | 2-32 | 5-38 | 11-62 | 1-13 | 0-9 | 0 |
| **1984** | | | | | | | | | | | | |
| Aphids/plant | - | 1.7±0.6 | 1.4±0.6 | 2.8±0.8 | 2.5±0.6 | 10.3±1.9 | 13.0±1.9 | 18.3±2.2 | 4.5±0.8 | 0 | | - |
| Min.-Max. | - | 0-5 | 0-6 | 0-9 | 0-7 | 0-24 | 6-31 | 4-32 | 1-12 | 0 | | - |
| **1985** | | | | | | | | | | | | |
| Aphids/plant | - | 0 | 1.3±0.4 | 3.3±0.7 | 4.7±1.2 | 32.0±4.1 | 58.7±7.4 | 31.2±4.7 | 29.1±3.6 | 2.1±0.6 | | 0 |
| Min.-Max. | - | 0 | 0-5 | 0-7 | 0-14 | 12-72 | 25-115 | 11-73 | 7-58 | 0-7 | | |

[a] N = 15, Mean ±S.E.

# CHAPTER III

## PART III

Economic injury level for the Colorado potato beetle,

*Leptinotarsa decemlineata* (Say)

(Coleoptera:Chrysomelidae) on potato in Manitoba

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## ABSTRACT

In a plot of potato cv. Norland, densities of the Colorado potato beetle, _Leptinotarsa decemlineata_ (Say), were manipulated on individually caged plants so that, throughout the growing season, each plant was exposed to a constant ratio of the density in an experimental field plot. There was a linear relationship between yield and beetle density in 1983 and 1985, and a curvilinear relationship in 1984. Sampling of growers' fields of potatoes provided information on yields when insecticides were used. From estimates of the cost and efficacy of such treatments a decision making model was developed. The relationship of X=A/2.2865 where A = [(cost of pest control per ha/market price of crop per kg)/yield from growers' crop kg per ha] 100 and X = number of Colorado potato beetle larvae per plant at the first bloom stage was used to establish an economic injury level.

# INTRODUCTION

The Colorado potato beetle, Leptinotarsa decemlineata (Say) is a major pest of potato in Manitoba (Cole 1951) where it normally has one generation per year on early maturing potato cultivars (Senanayake 1986). If uncontrolled, the Colorado potato beetle may completely defoliate potato plants, therefore potato growers frequently apply insecticides with little knowledge of pest numbers or of the economic benefits of control measures.

The impact of Colorado potato beetle on potato yield has been studied extensively. Hare (1980) reported that yields are little affected by relatively severe insect defoliation early or late in the season, whereas moderate defoliation at other times causes a considerable reduction in yield. Similar conclusions were made in mechanical defoliation studies (Murphy and Goven 1962; Cranshaw and Radcliffe 1980; Shields and Wyman 1984). However, these results are difficult to apply to pest control under field situations because they do not take into account the season-long nature of the insect-plant interaction. Ferro et al. (1983) took this into consideration when selecting control strategies that maximize net return to growers. Their data provide the base for developing economic injury levels and economic threshold levels for Colorado potato beetle. Logan and Casagrande (1980) developed an algorithm using the density of Colorado potato beetle larvae to predict yields. However, there is little experimental evidence to provide workable economic injury levels or threshold levels that would enable growers to make economically sound decisions about Colorado potato beetle control.

The purpose of this study is to quantify the impact of season-long infestations of Colorado potato beetle field populations on the yield of an early-maturing potato cultivar and so establish the economic injury level in Manitoba.

# MATERIALS AND METHODS

Field densities of Colorado potato beetle, Leptinotarsa decemlineata (Say) on potato cv. Norland were determined by a whole plant bag sampling method (WPBS) at weekly intervals in an experimental (insecticide free) plot at Morden, Manitoba in 1983-1985 (Senanayake 1986). In WPBS randomly selected plants were rapidly enclosed in cloth bags and removed to the laboratory for insect counting.

Potatoes of the same cultivar were grown 1.8m apart at the University of Manitoba, Winnipeg. The plot was prepared and treated the same way as the plot at Morden. Certified seed pieces (40-55g) were manually seeded on 27 May 1983, 28 May 1984 and 1985. Plants were individually caged as soon as they emerged. Cages (Fig. 1) were 0.6x0.6m and 1m high and were wood-framed and covered with white nylon netting (28 meshes per cm). On opposite sides of each cage there were 15 cm diameter sleeves 0.5m above ground level, to give access. Earth was banked against the bottom of the cages to prevent insect entry or exit.

In 1983, 1984 and 1985 caged plants were subjected to one of four treatments arranged in a completely randomized design. One treatment was a Colorado potato beetle free control. In the remaining three treatments, densities of beetles in the cages were manipulated so that throughout the season plants were exposed to a constant multiple of the mean density of Colorado potato beetles found in the experimental plot at Morden. Each week the proportion of early larvae (first and second instars), late larvae (third and fourth instars) and adults in each cage was adjusted to be the same as that found in WPBS of that week. The uninfested control treatment was replicated ten times in 1983 and 1984;

all other treatments were replicated five times in each season.

In 1985, a set of experiments with constant numbers of larvae and adults on caged plants was conducted in which there were six treatments arranged in a completely randomized design, with three replicates. Infestation periods coincided with the population pattern observed in the field.

At the same time as commercial harvesting, all caged plants, and 30 randomly selected plants from the experimental plot at Morden, were harvested. From two nearby growers' fields of the same cultivar 30 randomly selected plants were harvested in 1983, and 60 plants in 1984 and 1985. The quantity and quality of yield was assessed for each plant harvested.

The yields obtained at each location were separated into marketable tubers (more than 5.8 cm in diameter) and cull tubers (less than 5.8 cm in diameter) (Canada Department of Agriculture 1972); only the marketable yield, hereafter referred to as yield, was considered in the analysis. Data were analysed by analysis of variance and by step-up multiple regression (Proc. GLM, pp. 433-506; Proc. Reg, pp. 655-710, SAS Institute 1985). A significance level of $P \leq 0.05$ was adopted unless otherwise stated.

# RESULTS AND DISCUSSION

In cage studies in all three years, there was a reduction in yield with increasing Colorado potato beetle density (Table 1). Colorado potato beetle feeding resulted in small tubers that were not marketable (Fig. 2), and this is responsible for the decrease in number of marketable tubers with increasing density (Table 1).

There was a linear relationship between density of Colorado potato beetle and yield in 1983 and 1985 (Fig. 3). In 1984, there were relatively high field densities of Colorado potato beetle and a nonlinear relationship. The regression accounted for 98.7%, 99.9% and 99.7% of the among-treatment variation in 1983, 1984 and 1985, respectively (Table 2).

In constant density studies in 1985 (Fig. 4), there was a linear relationship between insect density and mean yield per plant for the treatments with 0, 1, 2, 4 or 6 insects throughout the season ($Y = 1.62-0.14X$, $F = 334.7$, $df = 1, 3$). The regression accounted for 99.1% of the among-treatment variation. Comparison of the control against each treatment (one-tailed Dunnett's test (Dunnett 1955)) showed a significant reduction in yield at 4 insects per plant and at 6 insects per plant throughout the season.

In growers' fields the densities of Colorado potato beetle were very low most of 1983-1985 (Senanayake 1986). However, yields in the cages, in the absence of insects (Table 1), were about 50% greater than that in growers' fields (Table 3) and so it was necessary to examine how applicable results from the cage system were to the field. The regression equations in Fig. 3 were converted to predict the percent reduction in yield at field density. These predictions were compared with yields in the growers' fields and in the experimental plot (Table 3). The percent yield reductions associated with the absence of insecticides were very close to those predicted from the regression equations.

Having thus validated the results from the cage study, the regression equations (Fig. 3) were applied to growers' fields to determine the economic injury level. To provide a yield-defoliation model, the field densities in all three years (Table 1) and constant densities with 1, 2, 4 or 6 insects throughout the 1985 season (Fig. 4) were converted to a common unit of impact by utilizing published data (Tamaki and Butt 1978) on foliage consumption. The estimates used for foliage consumed were: early larvae 0.44 $cm^2$ per day, late larvae 3.60 $cm^2$ per day, adults 6.87 $cm^2$ per day. Analysis of covariance revealed that slopes for the yield parameters were not significantly different between years and so the data were pooled for calculation of a common regression line between log percent yield and the estimated amounts of foliage consumed by larvae and adults (Fig. 5). The significant linear regression ($F = 509.8$, df = 1, 11, $P \leq 0.0001$), accounted for 97.9% of the among-treatment variation.

The yield-defoliation model for plants exposed to Colorado potato beetle throughout the season, predicts the percent yield reduction at a known level of defoliation. However, a growers' decision to spray insecticides to control Colorado potato beetles is based on the number of larvae per plant. To provide a density related decision-making model, the percent yield reduction was related to the peak density of larvae (Table 1) in all three years. The slopes for the yield parameters were not significantly different (analysis of covariance) between years. A significant linear relationship ($F = 73.9$, df = 1, 7, $P \leq 0.0001$) was obtained from analysis of the pooled data (Fig. 6). The regression accounted for 91.3% of the among-treatment variation and was used for calculating the economic injury level. The estimate of economic injury level at the peak density of larvae is justifiable as early defoliation has little effect on yield (Hare 1980) and also insecticide application prior to the peak can result in poor control of Colorado potato beetles (Senanayake 1986).

To calculate an economic injury level it was necessary to know the amount of yield loss that constitutes minimum economic damage or "gain threshold" (Ogunlana and Pedigo 1974). The following formula was used to calculate gain threshold:

$$\text{Gain threshold kg/ha} = \frac{\text{cost of pest control/ha}}{\text{market price of crop/kg}}$$

The gain threshold was expressed as a percent of the yield from a commercial crop.

$$\text{i.e.} \quad \frac{\text{gain threshold kg/ha}}{\text{yield from commercial crop kg/ha}} \times 100 = A$$

Any reduction in yield above A justifies the insecticidal control measures. Substituting A in the density-related regression equation (Fig. 6) to calculate economic injury level, $X = A/2.2865$ where X corresponds to the lowest population density of larvae that will cause economic damage and is the estimate of the economic injury level.

The economic injury level is a dynamic parameter that varies depending on A or its primary determinants, such as market price, control costs and potential yield (Pedigo et al. 1986). Giving single values for an economic injury level and extrapolating to other seasons and conditions can be misleading. This could be overcome by considering a range of values for economic injury level for change in yield potential and control costs. Table 4 provides a range of values of economic injury level at the time of peak density of larvae. It was observed in all three years that the peak density of larvae [52-56 dpp (days post planting)] coincided with the first bloom stage (Senanayake 1986). Therefore the estimates of economic injury level are applicable at the first bloom stage.

The present study shows that the potato plants have considerable capacity to recover from short-season defoliation (Fig. 4). Plants defoliated by Colorado potato beetle for over four week period early in the season (early-July to early-August), are less able to compensate for damage than those defoliated late in the season (early-August to early-September). The study also revealed that the potato yields are markedly affected by continuous defoliation imposed by Colorado potato beetle present throughout the season (Fig. 5). Although plants might have a potential to compensate for some damage at a particular stage of growth, it appears that plants are less able to compensate when defoliation continues.

Other researchers have examined the effect of short-season defoliation by Colorado potato beetle on potato yields. Hare (1980) in Connecticut, using a late-maturing cultivar (Katahdin), allowed defoliation by Colorado potato beetle to occur over two week period for seven discrete periods. He observed yield reductions only in the period represented by one week past full bloom (mid-July) when summer adults emerge and begin oviposition . Cranshaw and Radcliffe (1980) examined the effect of simulated insect defoliation on early- and late-maturing potato cultivars in Minnesota. They found that injury to plants at mid-season results in greatest yield reductions. Early- or late-season defoliation had less effect. These conclusions are similar to those of Wellik et al. (1981); Shields and Wyman (1984). Their data aid in understanding how the potato plant responds to defoliation, but they do not consider the effect of season-long defoliation.

Similar findings to that of the present study were reported by Ferro et al. (1983) in Massachusetts. They reported that it is justifiable economically to control summer larvae and adults on a medium-early maturing cultivar (Superior). They selected the insecticide spray regime at which maximum benefits are realised as the economic threshold level of Colorado potato beetle. However they did not establish a distinct threshold. Martel et al. (1986) considered an economic threshold of 20 late larvae per plant based on field observations, for medium-maturing cultivars (Kennebec) to develop a sequential sampling plan for Colorado potato beetle in Southwestern Quebec. The present experimental results indicated that peak larval density of 20 per plant would reduce marketable yield by 45.8% in an early maturing cultivar (Norland). Therefore, Martel et al.'s estimate of economic threshold is far too high for practical applications. Logan and Casagrande (1980) in Kingston, U.S.A. using comparable experimental conditions to the present study derived a linear relationship for the yield loss and the density of Colorado potato beetle larvae for the cultivar "Superior". However, their estimation of insect densities were made by integrating the density over physiological time and also their work does not provide an economic injury level or economic threshold for Colorado potato beetle.

The present study provides a density related relationship based on number of larvae per plant to estimate the economic injury level of Colorado potato beetle on Norland potatoes. Although the economic injury level represents the critical level of damage relative to current biological and economic circumstances, the operable decision criterion is the economic threshold (Pedigo et al. 1986). Because the economic threshold considers the proper timing of a control, an implicit risk is involved with assuming that pest-induced injury will reach or exceed economic injury level. In most situations where pesticides are used, the economic injury level equates the economic threshold since there is no time delay in the control operation. Therefore, the economic injury level will provide growers with a basis for making an economically sound decision on whether to apply insecticides in July to control Colorado potato beetle populations on Norland. Furthermore, the economic injury level of Colorado potato beetle is useful in evaluating the performance of a control program. However, it must be stressed that it is doubtful these data can be used for other cultivars or for localities where the relative phenology of the plant and the Colorado potato beetle are markedly different.

## ACKNOWLEDGEMENTS

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Table 1. Effect of 4 field densities of Colorado potato beetle populations at the peak time on potato yield (cv. Norland) in caged plants, 1983-1985

| | | Peak numbers per caged plants | | | | Marketable tubers per plant ± S.E. | |
|---|---|---|---|---|---|---|---|
| Field density | Number of replicates | Early instar larvae | Late instar larvae | All larvae | Adults | kg | Number |
| | | | 1983 | | | | |
| x0 | 10 | 0 | 0 | 0 | 0 | 1.57±0.18 | 7.20±0.55 |
| x0.5 | 5 | 7 | 5 | 12 | 9 | 1.02±0.18 | 5.20±0.49 |
| x1.0 | 5 | 13 | 11 | 24 | 17 | 0.68±0.13 | 4.00±0.45 |
| x2.0 | 5 | 26 | 22 | 28 | 34 | 0.00±0.00 | 0.00±0.00 |
| | | | 1984 | | | | |
| x0 | 10 | 0 | 0 | 0 | 0 | 1.35±0.08 | 6.70±0.34 |
| x0.5 | 5 | 10 | 12 | 21 | 27 | 0.30±0.01 | 2.60±0.25 |
| x1.0 | 5 | 20 | 24 | 41 | 53 | 0.12±0.04 | 1.00±0.32 |
| x2.0 | 5 | 40 | 48 | 82 | 106 | 0.00±0.0 | 0.00±0.00 |
| | | | 1985 | | | | |
| x0 | 5 | 0 | 0 | 0 | 0 | 1.61±0.15 | 7.60±0.60 |
| x0.25 | 5 | 2 | 4 | 6 | 1 | 1.51±0.11 | 8.00±0.45 |
| x0.5 | 5 | 5 | 9 | 12 | 2 | 1.35±0.08 | 6.60±0.51 |
| x1.0 | 5 | 9 | 17 | 23 | 3 | 1.11±0.15 | 5.40±0.51 |

Table 2. Analysis of variance (ANOVA) for the regression of yield of potatoes (cv. Norland) on the Colorado potato beetle densities, 1983-1985

| Source | df | SS | F |
|---|---|---|---|
| | | Year 1983 | |
| Within densities | 21 | 4.038 | |
| Among densities | 3 | 8.800 | 15.28 |
| Linear regression | 1 | 8.688 | 155.14 |
| Residual | 2 | 0.112 | 0.29 |
| | | Year 1984[a] | |
| Within densities | 21 | 0.001 | |
| Among densities | 3 | 1.804 | 12628.00 |
| Linear regression | 1 | 1.802 | 1802.00 |
| Residual | 2 | 0.002 | 21.00 |
| | | Year 1985 | |
| Within densities | 16 | 1.285 | |
| Among densities | 3 | 0.708 | 8.82 |
| Linear regression | 1 | 0.706 | 706.00 |
| Residual | 2 | 0.002 | 0.01 |

[a]ANOVA based on $\log_{10}$ transformed data.

Table 3. Mean yield (± S.E.) of potatoes (cv. Norland) in growers' fields and experimental plot, and percent loss in yield in the field and in the caged plants, 1983-1985

| | Yield | | | |
|---|---|---|---|---|
| Year | Growers' kg/plant | Experimental kg/plant | % Loss in the field | % Loss in[a] the caged plants |
| 1983 | 0.95±0.07 | 0.48±0.04 | 49 | 52 |
| 1984 | 0.89±0.04 | 0.14±0.03 | 84 | 94 |
| 1985 | 0.86±0.05 | 0.63±0.05 | 26 | 32 |

[a]Predicted at field density using the regression equation in Figure 3.

Table 4. Calculated economic injury levels for changes in yield and control costs

| Control costs[a] $/ha | Expected yield[b] (metric tons/ha) | | |
|---|---|---|---|
| | 15 | 20 | 25 |
| 16 | 1 larva/4 plants | 1/6 | 1/7 |
| 36 | 1/2 | 1/3 | 1/3 |
| 56 | 1 | 1/2 | 1/2 |

[a]Includes cost of insecticides ($/ha) and cost of ground application ($6/ha).

[b]Average market value is $200 per metric ton.

Figure 1. Individually caged potato plant (cv. Norland) on campus at the University of Manitoba, Winnipeg.

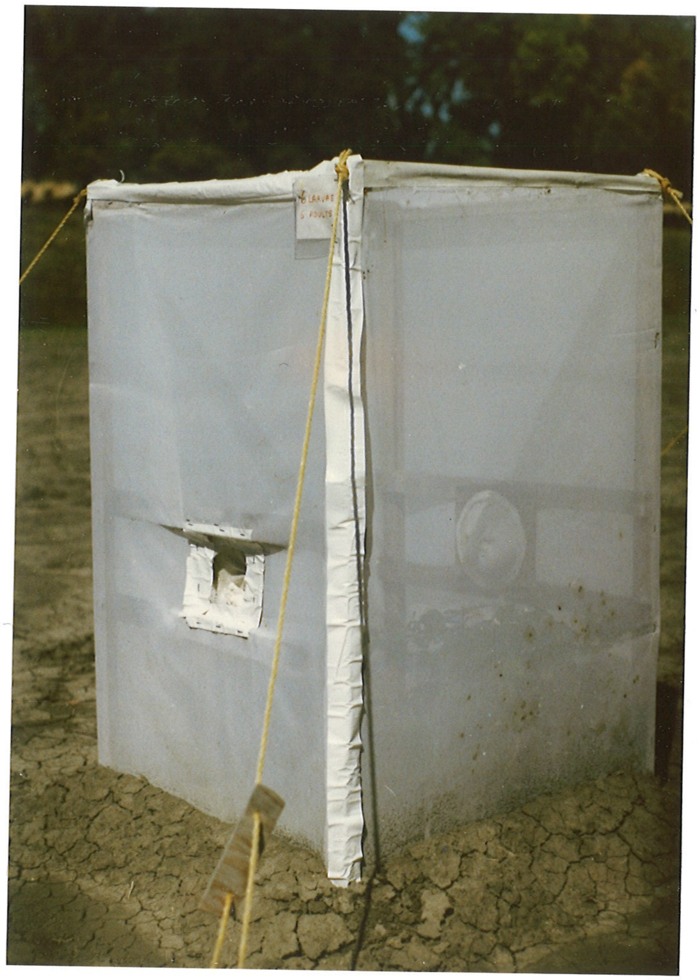
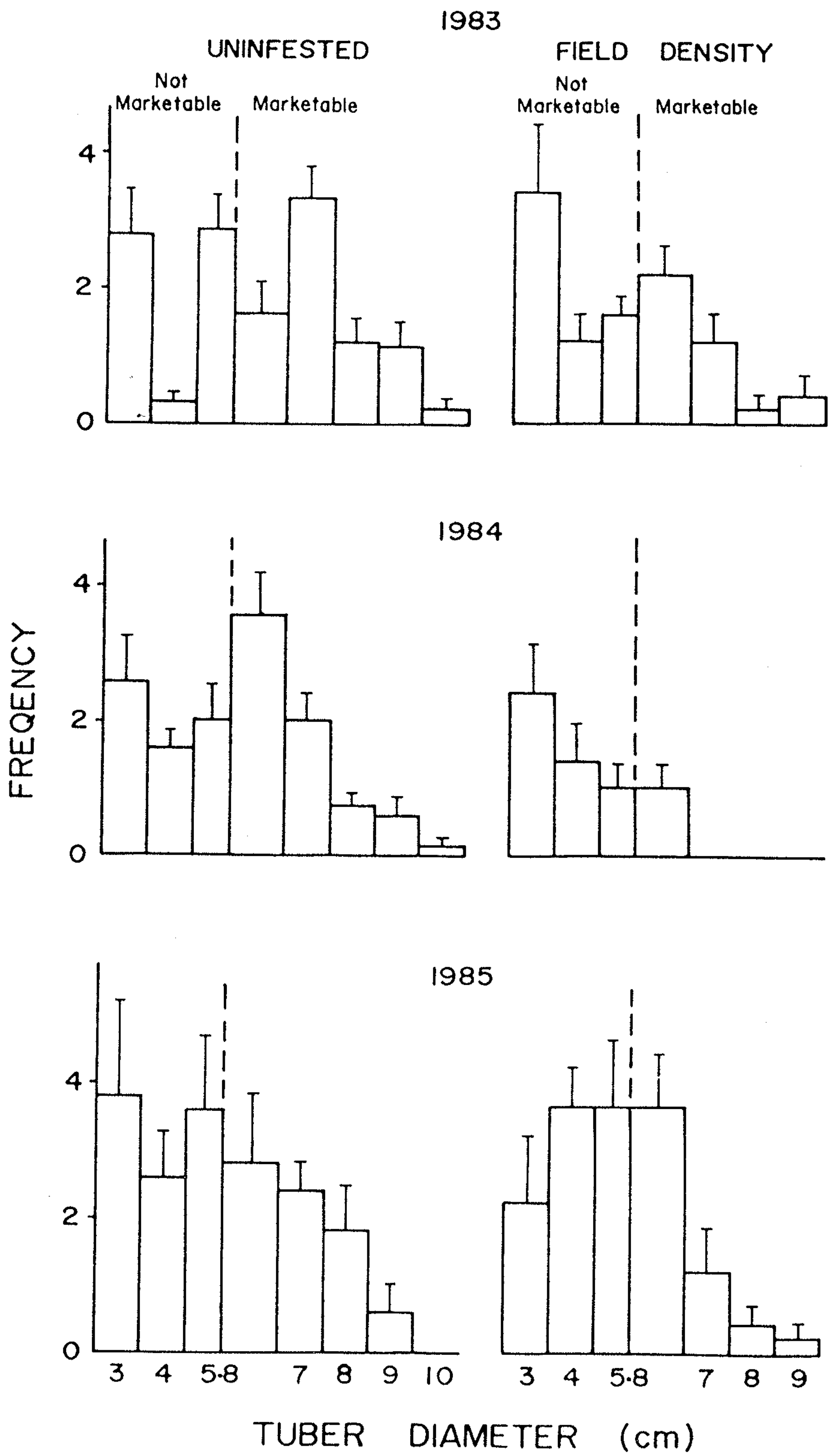
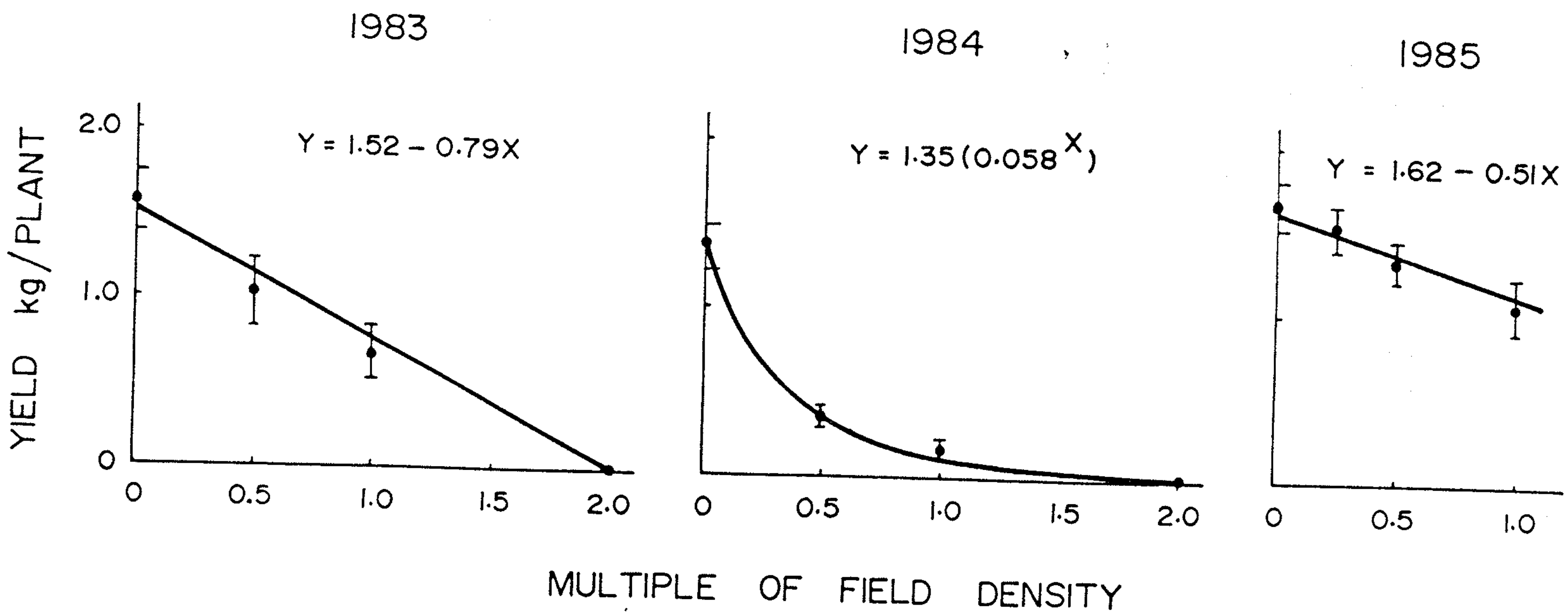


Figure 2. Frequency distribution of the tuber size (mean ± S.E.) obtained from individually caged plants, uninfested and exposed to field density of Colorado potato beetle, 1983-1985.



1983
UNINFESTED
FIELD DENSITY
Not Marketable
Marketable
Not Marketable
Marketable
1984
1985
FREQENCY
0
2
4
3
4
5-8
7
8
9
10
3
4
5-8
7
8
9
TUBER DIAMETER (cm)

Figure 3. Relationship of yield (mean ± S.E.) to density of Colorado potato beetles for individually caged plants, 1983-1985.



1983
1984
1985
Y = 1.52 – 0.79X
Y = 1.35 (0.058^X)
Y = 1.62 – 0.51X
YIELD kg/PLANT
2.0
1.0
0
0
0.5
1.0
1.5
2.0
MULTIPLE OF FIELD DENSITY

Figure 4. Effect of defoliation by 7 constant densities of Colorado potato beetle populations on potato yield (cv. Norland) in caged plants, 1985.

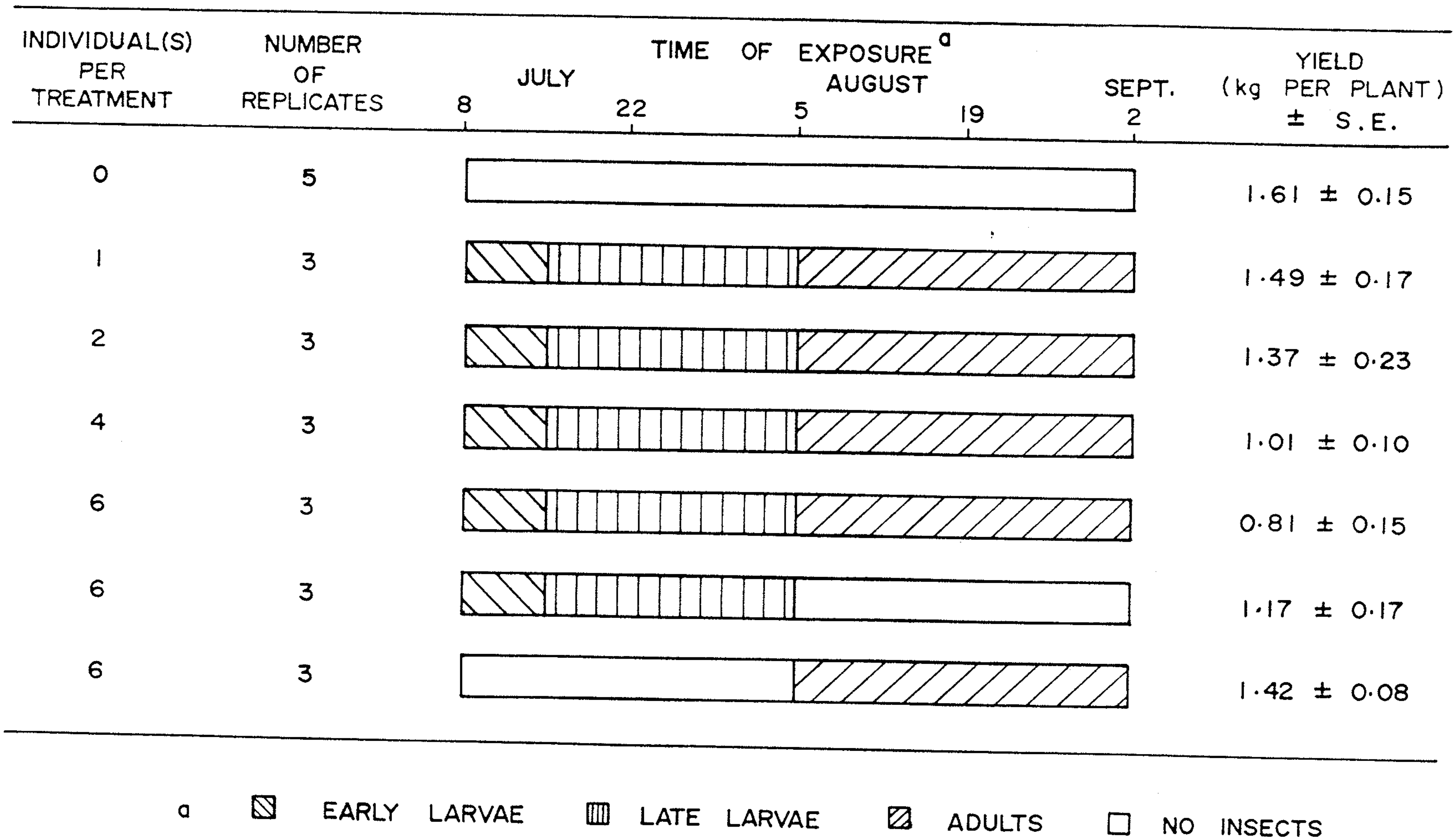
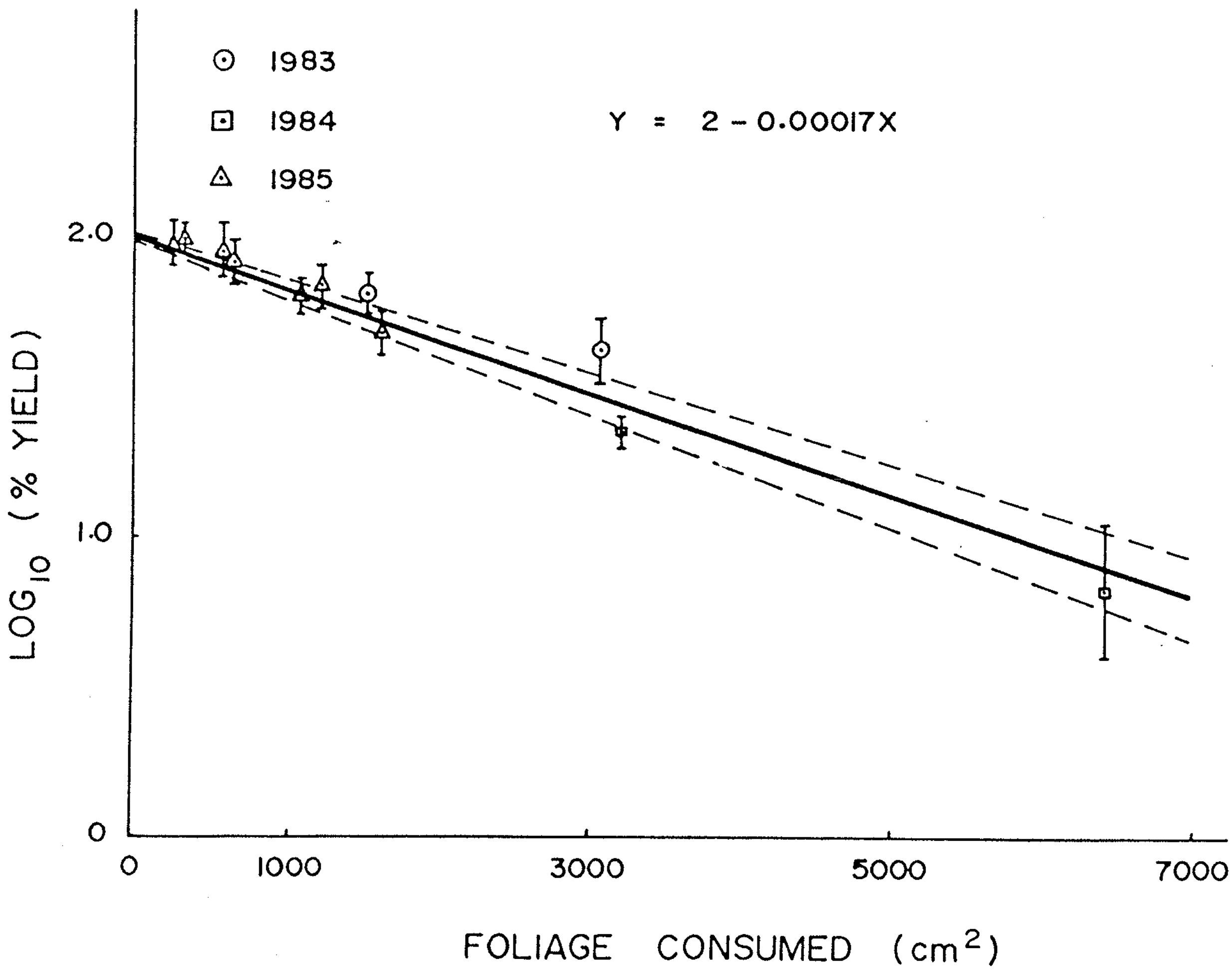
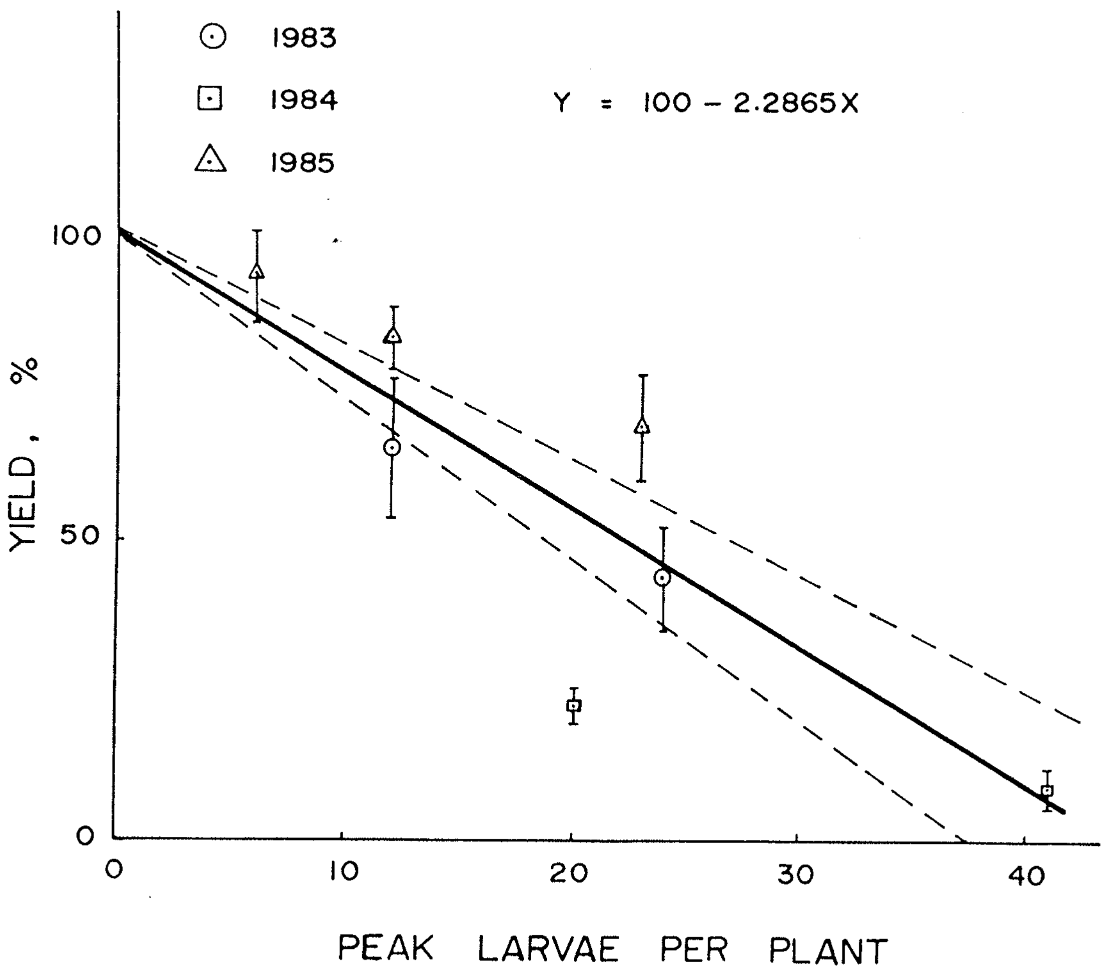

INDIVIDUAL(S) PER TREATMENT
NUMBER OF REPLICATES
TIME OF EXPOSURE[a]
JULY
AUGUST
SEPT.
8
22
5
19
2
YIELD (kg PER PLANT) ± S.E.
0
5
1.61 ± 0.15
1
3
1.49 ± 0.17
2
3
1.37 ± 0.23
4
3
1.01 ± 0.10
6
3
0.81 ± 0.15
6
3
1.17 ± 0.17
6
3
1.42 ± 0.08
a
EARLY LARVAE
LATE LARVAE
ADULTS
NO INSECTS

Figure 5. Relationship of yield, as a percentage of control yield, (means ± S.E.), and estimated total amount of foliage consumed by Colorado potato beetle population for individually caged plants in 1983-1985, with 95% confidence limits of the estimated mean yield.



1983
1984
1985
Y = 2 - 0.00017X
2.0
1.0
0
LOG10 (% YIELD)
0
1000
3000
5000
7000
FOLIAGE CONSUMED (cm2)

Figure 6. Relationship of yield, as a percentage of control yield (mean ± S.E.) and peak larval density for individually caged plants in 1983-1985, with 95% confidence limits of the estimated mean yield.


1983
1984
1985
Y = 100 - 2.2865X
100
50
0
YIELD, %
0
10
20
30
40
PEAK LARVAE PER PLANT

# CHAPTER III

## PART IV

Economic injury level for the potato flea beetle, (Coleoptera:Chrysomelidae) on potato and a comparison of plant response to defoliators

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## ABSTRACT

In a plot of potato cv. Norland, densities of potato flea beetle, Epitrix cucumeris (Harris), were manipulated on individually caged plants so that throughout the growing season, each plant was exposed to a constant ratio of the density in an experimental field plot. In cages there was no significant reduction in yield even at twice the field density observed in 1983-1985. There was a cubic polynomial relationship between percent yield and peak adult density because at low insect densities, the plants overcompensated or compensated for insect injury. This region of compensation included all the densities observed in the field. For decision making, the relationship of percent yield to the number of feeding punctures on the undersurface of a bottom leaflet at two weeks past first bloom was used. The estimated range of economic injury levels for varying control costs and yield potentials under Manitoba growing conditions is 67-75 feeding punctures per leaflet.

The potato plant showed tolerance at low levels of defoliation to potato flea beetle but not to Colorado potato beetle, Leptinotarsa decemlineata (Say). However, response of the plant at high levels of defoliation by these species was very similar.

# INTRODUCTION

The potato flea beetle, *Epitrix cucumeris* (Harris) is an abundant defoliator of potatoes in Manitoba where it has one generation per year on early maturing potato cultivars (Senanayake 1986b). It has caused growers' concern mainly because of the conspicuous nature of the feeding scars. In addition to the defoliation by adults, the larvae feed on tubers causing wounds (Cole 1951) which could affect their marketability.

Knowledge of the economic impact of potato flea beetles on yield is limited. Thompson (1984, 1985) related the number of feeding holes to the yield of several potato cultivars, and found that for some cultivars there was a significant yield reduction at field densities of potato flea beetle in Prince Edward Island. However, there is very little published information available to provide workable economic injury levels or economic threshold levels for potato flea beetle.

The purpose of this study is to quantify the impact of potato flea beetle field populations maintained on individually caged plants throughout the growing season on yield, and to develop appropriate models to establish the economic injury level. The results of the present study are compared with those of Senanayake (1986c) to examine whether the potato plant is differentially susceptible to defoliation by potato flea beetle and Colorado potato beetle, *Leptinotarsa decemlineata* (Say), respectively.

# MATERIALS AND METHODS

Field densities of potato flea beetle on potato cv. Norland were determined weekly by a whole plant bag sampling method (WPBS) in an experimental (insecticide free) plot at Morden, Manitoba in 1983-1985 (Senanayake 1986b). In WPBS randomly selected plants were rapidly enclosed in cloth bags and removed to the laboratory for insect counting.

A cage study, was undertaken on the campus of the University of Manitoba, Winnipeg in 1983-1985; the methods used were similar to those of Senanayake (1986c). Plants were individually caged as soon as they emerged. Densities of adult potato flea beetles in the cages were manipulated so that throughout the season plants were exposed to a constant multiple of the density of beetles found in a field plot at Morden. Each week, the number of adult potato flea beetles in the cage was adjusted to a constant ratio of the mean found in WPBS of that week.

Potato flea beetle injury to caged plants was assessed weekly in three replicates of each treatment. The potato plant was divided into top, middle and bottom strata with an approximately equal number of leaves in each stratum. In 1984, a terminal leaflet was randomly selected and sampled from each stratum. In 1985, only bottom terminal leaflets were sampled. The number of holes chewed through and the scars on both upper and underside of the leaflet was recorded. A feeding hole or scar 1 $mm^2$ or less was considered as one feeding puncture. The equivalent number of 1 $mm^2$ feeding punctures in larger holes were assessed using graph paper. Early in the season up to 57 days post planting, counting was done without removing the leaflets and thereafter leaflets were picked and taken to the laboratory for counting.

Comparative estimates of feeding injury were made in growers' fields and in an isolated plot of cv. Norland at Morden in 1985. Full details of growers' fields are given in Senanayake (1986b). The isolated plot was 8 rows wide 10m long with 1m spacing between rows and 0.3m within rows, and separated from an adjacent experimental plot by a 3m potato free area. The isolated plot was prepared and treated the same way as the experimental plot. In the isolated plot, to assess the potato flea beetle feeding injury, all stages of Colorado potato beetle were removed by hand weekly. Every week 15 plants were randomly selected from growers' fields and from the isolated plot, and the potato flea beetle feeding punctures on one bottom terminal leaflet of each plant was counted.

All caged plants were harvested at the same time as commercial harvesting. In 1984, at the time of harvest, the leaflets 10 $cm^2$ or larger on insect-free control caged plants were counted. In all three years, the quantity and quality of yield was assessed for each plant harvested. Only the weight of marketable tubers 5.8 cm in diameter or larger (Canada Department of Agriculture 1972), hereafter referred to as yield, was considered in the analysis. Data were analysed by analysis of variance and by step-up multiple regression (Proc. GLM, pp. 433-506; Proc. Reg, pp. 655-710, SAS Institute 1985). A significance level of $P \leq 0.5$ was adopted unless otherwise stated.

# RESULTS

In 1983, the caged plants showed an increase in yield at low densities of potato flea beetles (Table 1). In all three years, insects up to twice the field density had no significant (two-tailed Dunnett's test (Dunnett 1955)) impact upon the yield. However, yields at four times and eight times field densities of potato flea beetle (Table 1) were significantly lower than the control. Potato flea beetle larval injury observed on some tubers was barely visible and did not cause a down-grading of tubers.

The yield as a percentage of the yield on insect free controls was related to the peak density of adults in all three years. Analysis of covariance based on a cubic polynomial regression revealed that the slopes for the yield parameters did not differ significantly among years. A significant cubic polynomial relationship ($F = 74.3$, $df = 3, 8$, $P<0.0001$) was obtained from the analysis of the pooled data (Fig. 1). The regression accounted for 90.3% of among-treatment variation. There was a considerable region of overcompensation and compensation (Pedigo et al. 1986) in the curve of yield response to potato flea beetle density. The region included all the densities observed in the field.

To provide a decision-making model for situations where there is an economic loss in yield, the potato flea beetle feeding injury at two weeks past first bloom in 1984 [66 dpp (days post planting)] and 1985 (70 dpp) was related to yield. In 1984, regressions of percent yield on the number of feeding punctures on the upperside of the leaflet in the top stratum ($Y = 112.54-0.90X$, $r^2 = 0.40$, $n = 12$), middle stratum ($Y = 101.40-0.40X$, $r^2 = 0.51$, $n = 12$), bottom stratum ($Y = 109.98-0.27X$, $r^2 = 0.54$, $n = 12$), and feeding punctures on the underside of the leaflet in the top stratum ($Y = 114.12-0.89X$, $r^2 = 0.47$, $n = 12$), middle stratum ($Y = 105.96-0.43X$, $r^2 = 0.54$, $n = 12$), bottom stratum ($Y = 111.35-0.26X$, $r^2 = 0.56$, $n = 12$) were performed. The feeding injury on the underside of the bottom leaflets accounted for the most variation in the Y observations. Although the assessment of feeding injury required removal of leaflets, this did not cause a significant difference in yield when compared with plants where no leaflets were removed, in 1984 ($F = 0.01$, $df = 1, 12$) and 1985 ($F = 1.53$, $df = 1, 9$).

In 1984 and 1985, the slopes for the yield parameters were not significantly different (analysis of covariance) between years, and the data were pooled for calculation of a common regression line between the percent yield and the feeding injury on the underside of the bottom leaflets (Fig. 2). The significant ($F = 35.7$, $df = 3, 33$, $P<0.0001$) cubic polynomial relationship obtained from analysis of the pooled data was used for calculation of economic injury level.

To estimate an economic injury level it was necessary to know not only the rate of yield reduction by potato flea beetle but also the amount of yield loss that constitutes minimum economic damage or the "gain threshold" (Ogunlana and Pedigo 1974). The following formula was used to calculate gain threshold:

$$\text{Gain threshold kg/ha} = \frac{\text{cost of pest control/ha}}{\text{market price of crop/kg}}$$

The gain threshold was expressed as a percent of the yield from a commercial crop.

i.e. $\dfrac{\text{gain threshold kg/ha}}{\text{yield from commercial crop kg/ha}} \times 100 = A$

The economic injury level is the number of feeding punctures on the underside of a bottom leaflet (X) that would reduce the percent yield by A. Substituting A in the regression equation (Fig. 2),

$$A = 100 + 0.22X - 3.79 \times 10^{-3} X^2 + 7.12 \times 10^{-6} X^3$$

Where X is the estimate of the economic injury level at two weeks past first bloom stage. Since economic injury level is a dynamic parameter that varies depending on A, a range of values for economic injury level calculated for change in yield potential and control costs are provided in Table 2.

Although the injury was assessed in caged plants, the mean estimates of feeding punctures in these plants (exposed to field densities of potato flea beetles) and in the isolated plot (Table 3) were not significantly different (unpaired t-test) when tested for each week. This indicated that feeding characteristics of the species were not affected by caging. However, at the beginning and end of the season there were significantly more (unpaired t-test) feeding punctures in the cages than in the growers' fields.

The relationship between percent yield and seasonal defolition by potato flea beetle and by Colorado potato beetle (Senanayake 1986c) is shown in Fig. 3. The amount of defoliation by potato flea beetle was estimated by multiplying the total area of feeding punctures per leaflet at the end of 1984 and 1985 seasons, and the total number of leaflets per plant [(570.6 $\pm$ 32.2) (mean $\pm$ S.E.)] in 1984. The plants showed compensation at low levels of defoliation to potato flea beetle but not to Colorado potato beetle (Fig. 3). However, the response of the potato plant at high levels of defoliation by potato flea beetle and Colorado potato beetle were very similar.

## DISCUSSION

Density estimates of potato flea beetles using monitoring methods such as visual or sweepnet sampling show considerable seasonal bias (Senanayake 1986a) and therefore may mislead growers. On the other hand the number of feeding punctures per leaflet provides a practical method of assessing injury and therefore was used in the estimation of economic injury level.

The timing of insecticide application is important in potato flea beetle control. Study of the pattern of population growth for the species (Senanayake 1986b) revealed that the most appropriate time is two weeks past first bloom stage. Early application of insecticides when the summer generation is in the soil can miss some insects whereas if the application is too late injury may have already occurred. Also the selection of this time was practical for the growers because their late insecticide applications for control of pests were made around this time (Senanayake 1986b).

The potato plant has a considerable capacity for compensation when exposed to field densities of potato flea beetles in Manitoba (Fig. 1 and 2). The linear portion in the middle of the damage curve is used in calculating the economic injury level. At high levels of injury the cubic polynomial regression model indicates a yield increase which is probabaly not biologically realistic. This lack of realism has no practical importance because it occurs far beyond the region of the economic injury level.

Although plants exposed to field densities of potato flea beetle did not show significant yield reductions in Manitoba, Thompson (1984, 1985) reported reductions of up to 32% for different potato cultivars in

Prince Edward Island. He estimated the levels of defoliation by counting the feeding holes in the fourth terminal leaflet. The reduction in yield could be attributed to the estimated high levels of defoliation.

The present study provides a decision-making model (Fig. 2) that can be easily used by Norland growers to estimate the economic injury level for the potato flea beetle. The estimated range of economic injury levels under Manitoba growing conditions is 67-75 feeding punctures per leaflet at (Table 2) two weeks past first bloom. Although the economic injury level represents the critical level of damage relative to current biological and economic circumstances, the operable decision criterion is the economic threshold (Pedigo et al. 1986). Because the economic threshold considers the proper timing of a control, an implicit risk is involved with assuming that pest-induced injury will reach or exceed economic injury level. In most situations where pesticides are used, the economic injury level equates the economic threshold since there is no time delay in the control operation. Therefore, the economic injury level will provide growers with a basis for making a decision on whether to apply insecticides in late July or early August to control potato flea beetle populations. Also the economic injury level is useful in evaluating the performance of a control program. In 1985 potato flea beetle injury in the growers' fields (60.5 feeding punctures per leaflet) was lower than the economic injury level, therefore control measures were not necessary. The closeness of the potato flea beetle injury to the economic injury level exemplifies the importance of assessing the injury as the economic injury level will likely be exceeded in some years.

Response of the potato plant to potato flea beetle and Colorado potato beetle

The differential response of the potato plant to defoliation by potato flea beetle and Colorado potato beetle (Fig. 3) could be attributed to the feeding pattern of the species. The potato flea beetle feeds at all levels of the plant whereas the Colorado potato beetle often feeds on top leaves (Shields and Wyman 1984) including the growing points of the plant (personal observations). Since removal of the top leaves causes greater reduction in yield than the removal of either middle or lower leaves (Cranshaw and Radcliffe 1980; Shields and Wyman 1984), low levels of Colorado potato beetle feeding are more detrimental to yield than equivalent amounts of defoliation by potato flea beetles. It is possible that other factors, such as plant response to insect saliva, or lesion shape and size may also be involved in the differential response to potato flea beetle and Colorado potato beetle defoliation.

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Table 1. Effect of field densities of potato flea beetle populations at the peak time on potato yield (cv. Norland) in caged plants, 1983-1985

| Field density | Number of replicates | Adults/caged plants | Marketable yield (kg)/ plant ± S.E. |
|---|---|---|---|
| | | 1983 | |
| x0 | 10 | 0 | 1.57±0.18 |
| x0.5 | 5 | 30 | 1.64±0.13 |
| x1.0 | 5 | 59 | 1.80±0.23 |
| x2.0 | 5 | 118 | 1.48±0.11 |
| | | 1984 | |
| x0 | 10 | 0 | 1.35±0.08 |
| x1.0 | 5 | 47 | 1.33±0.09 |
| x2.0 | 5 | 94 | 1.19±0.05 |
| x4.0 | 5 | 188 | 0.61±0.05 |
| x8.0 | 5 | 376 | 0.29±0.04 |
| | | 1985 | |
| x0 | 5 | 0 | 1.61±0.15 |
| x1.0 | 5 | 99 | 1.46±0.15 |
| x2.0 | 5 | 198 | 1.34±0.07 |
| x4.0 | 5 | 396 | 0.70±0.11 |

Table 2. Calculated economic injury levels for changes in yield and control costs

| Control costs[a] $/ha | Expected yield[b] (metric tons/ha) | | |
|---|---|---|---|
| | 15 | 20 | 25 |
| | Feeding punctures/leaflet | | |
| 16 | 69 | 68 | 67 |
| 36 | 72 | 70 | 69 |
| 56 | 75 | 73 | 72 |

[a]Includes cost of insecticides ($/ha) and cost of ground application ($6/ha).

[b]Average market value is $200 per metric ton.

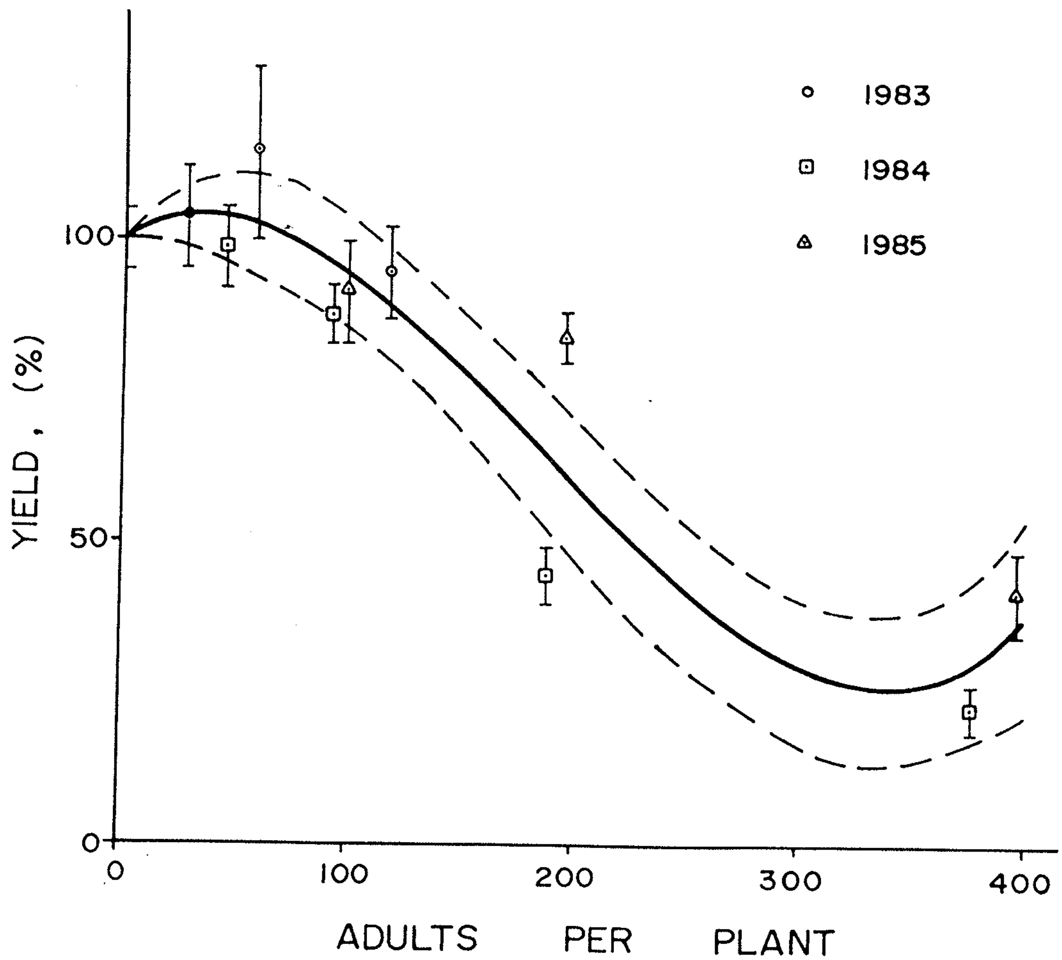
Table 3. Mean number (± S.E.) of feeding punctures on the underside of bottom leaflets exposed to field densities of potato flea beetles in 1985

| | Days post planting | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 25 | 35 | 42 | 49 | 56 | 63 | 70 | 77 | 84 |
| Caged plants[a] | 23.7 ±2.6 | 22.3 ±8.1 | 48.0 ±13.6 | 55.0 ±13.9 | 31.3 ±8.7 | 48.0 ±16.0 | 86.0 ±21.4 | 142.3 ±47.4 | 173.3 ±32.3 |
| Isolated plot[b] | 8.1 ±1.7 | 25.9 ±4.8 | 34.5 ±4.1 | 47.7 ±3.8 | 50.9 ±4.4 | 54.4 ±5.0 | 69.0 ±4.9 | 103.6 ±7.9 | 226.5 ±22.5 |
| Growers' fields[b] | 2.1 ±1.0 | 14.1 ±3.2 | 40.0 ±3.9 | 42.9 ±4.7 | 55.9 ±7.2 | 49.6 ±5.3 | 60.5 ±6.0 | 71.3 ±5.5 | 113.7 ±11.0 |

[a]N = 3

[b]N = 15

Figure 1. Relationship of yield, as a percentage of control yield (mean $\pm$ S.E.), and peak adult density ($Y = 100 + 0.21X - 3.17 \times 10^{-3} X^2 + 5.65 \times 10^{-6} X^3$) for individually caged plants in 1983-1985, with 95% confidence limits of the estimated mean yield.



1983
1984
1985
YIELD , (%)
100
50
0
0
100
200
300
400
ADULTS PER PLANT

Figure 2. Relationship of yield, as a percentage of control yield, and the feeding punctures per leaflet ($Y = 100 + 0.22X - 3.79 \times 10^{-3} X^2 + 7.12 \times 10^{-6} X^3$) for individually caged plants in 1984 and 1985, with 95% confidence limits of the estimated yield.

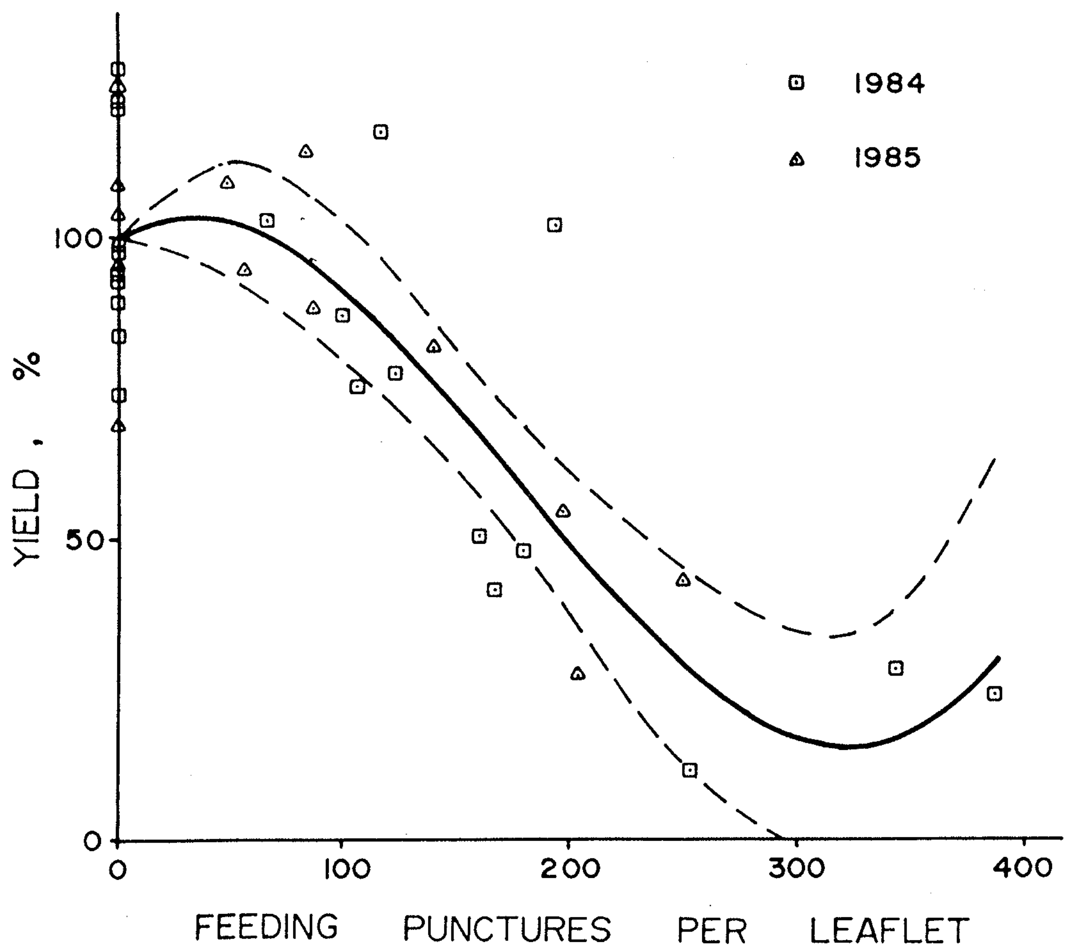
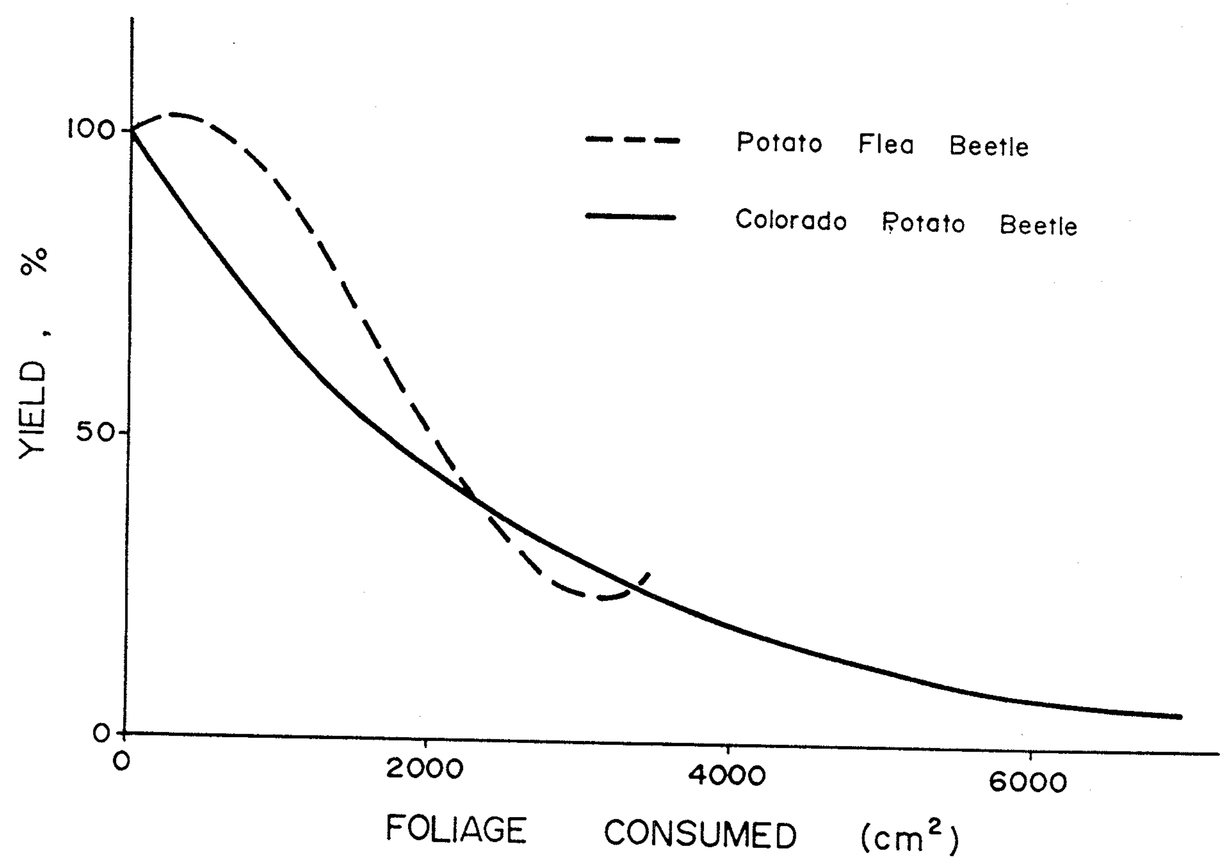

1984
1985
YIELD , %
100
50
0
0
100
200
300
400
FEEDING PUNCTURES PER LEAFLET

Figure 3. Relationship of yield, as a percentage of control yield, and the total amount of foilage consumed by potato flea beetle ($Y = 100 + 0.02\ X - 3.60 \times 10^{-5}\ X^2 + 7.05 \times 10^{-9}\ X^3$ and by Colorado potato beetle [$Y = 100\ (10^{-0.00017\ X})$] for individually caged plants.



Potato Flea Beetle
Colorado Potato Beetle
YIELD , %
100
50
0
0
2000
4000
6000
FOLIAGE CONSUMED (cm²)

# CHAPTER III

## PART V

## The influence of potato flea beetle upon common scab infection of potatoes

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## ABSTRACT

Manipulation of high densities of potato flea beetle, Eptrix cucumeris (Harris) on caged potato plants cv. Norland, increased the occurrence of common scab on potato. The actinomycete, Streptomyces scabies (Thaxter) Waksman and Henrici, was isolated from scab lesions. Close association of potato flea beetle larval injury and deep-pitted scab lesions was observed on infected tubers. It is suggested that the feeding activities of potato flea beetle larvae could have influenced the spread of scab on tubers.

# INTRODUCTION

The occurrence of the actinomycete, Streptomyces scabies (Thaxter) Waksman and Henrici, the causal agent of common scab on potatoes (Millard and Burr 1926) presents an economic problem because it reduces the grade and value of the affected tubers (Martin 1969). S. scabies causes both shallow and deep-pitted scab lesions on tubers (Archuleta and Easton 1981) which are characterized by raised, corky areas and by depressed areas, respectively (Hooker 1981). Common scab has no foliar or above ground symptoms (Rich 1968).

The constant presence of springtails and mites in scab lesions have been observed by Storch et al. (1978). They showed that these arthropods carry the common scab organism both on and in their bodies. Tests with several soil applied systemic insecticides have shown significant control of scab on tubers despite having little effect on the scab pathogen in vitro (Manzer et al. 1984). Potato flea beetle, Epitrix cucumeris (Harris), larvae (Schaal 1934); scab gnats, Pnyxia scabiei (Hopkins), oligochaetes and nematodes (Tamaki et al. 1976) have also been observed on scab lesions. However, the relationship between these soil-inhabiting arthropods and the incidence of scab infection on tubers is not known. The present study was carried out with an early maturing cv. Norland, which shows moderate resistance to common scab (Johansen et al. 1959; Lawrence 1974). The objective of the study was to determine whether potato flea beetle larvae have an effect on scab infection of potato tubers.

# MATERIALS AND METHODS

Certified seed pieces of cv. Norland were planted at the campus of the University of Manitoba and the plants were individually caged as soon as they emerged. The densities of insects in these cages were manipulated once each week so that throughout the season plants had either 0, 1X, 2X or 4X the density of potato flea beetles found in an insecticide-free plot of cv. Norland potatoes. The methods used to determine and manipulate insect numbers are given in Senanayake (1986a and 1986d). Caged plants were arranged in a complete randomized design and replicated five times for each treatment. Plants were harvested at the same time as commercial harvesting.

To determine the presence of scab pathogen _S. scabies_ on tubers with lesions, tubers were washed and disinfected by swabbing with 95% ethanol and setting it aflame. Tangential sections 1 mm thick and 10 mm wide were cut from scab lesions and macerated in a sterilized mortar with a few drops of physiological saline. Using a sterile glass rod 0.5 ml of the solution was spread on the surface of tyrosine-casinate-nitrate (TCN) agar medium (Menzies and Dade 1959) and incubated for two weeks in the dark at 21$^{o}$C.

To quantify the amount of scab, tubers were examined visually in the laboratory. Based on the percentage of tuber surface with scab, tubers were categorized into four damage classes; none (0%), trace (1-5%), moderate (6-20%) and severe (more than 20%).

# RESULTS

Brown to black melanin-type pigment on the TCN agar medium confirmed the presence of S. scabies on or in the scab lesions. These lesions were dark brown and consisted of depressed areas (Fig. 1), and were identified as deep-pitted scab. In most instances the scab lesions were observed around the channels caused by the potato flea beetle larvae (Fig. 1).

The severity of the scab infection on tubers exposed to the four densities of potato flea beetle are given in Table 1. Scab infection increased in frequency and severity with increasing insect density. Although the one tuber with severe scab had sufficient disfigurement for down-grading, the tuber was not in the marketable range [more than 5.8 cm in diameter (Canada Department of Agriculture 1972)]. Tubers with trace or moderate scab did not show sufficient disfigurement for down-grading.

# DISCUSSION

A direct relationship between the severity of scab infection and potato flea beetle density was observed. Increased occurrence of scab could have resulted from increased potato flea beetle larval activity. The larvae primarily feed on the root system and tubers causing wounds (Cole 1951). The scab pathogen, *S. scabies* could gain entrance to the tuber more easily through such wounds and also potato flea beetle larvae could spread the pathogen from soil to tubers or tuber to tuber (Hanson 1933; Schaal 1934).

Whether potato flea beetle larval injury makes the lesions appear deeper is not known. Generally, it is believed that the deep-pitted wounds are a result of combined action of chewing insects and the scab pathogen (Shands and Landis 1964). However, Tamaki et al. (1976) found that the potato scab gnat, *Pynxia scabiei* (Hopkins) which feeds primarily on fungi, does not cause deep-pitting. No differences were observed in the depth and width of the wounds between uninfested tubers and those infested with scab gnat.

Athough the potato flea beetle larval injury on the tubers remains largely unnoticed (Senanayake 1986d) complications may arise with the invasion of *S. scabies*. This can cause disfigurement of the tubers which makes them inferior in quality resulting in down-grading. The reduction in marketable tubers when associated with scab could result in a lower economic injury level for potato flea beetle. This would be more likely on cultivars more susceptible than Norland.

## ACKNOWLEDGEMENTS

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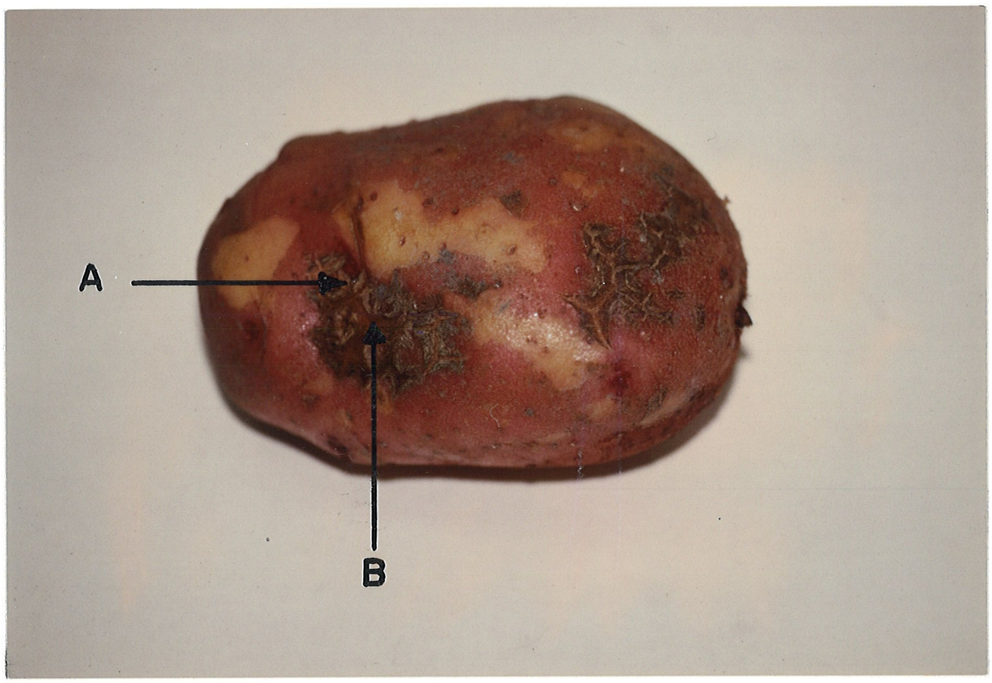
Table 1. The effect of 4 densities of potato flea beetles on common scab in potato tubers (cv. Norland) in 1985

| Peak numbers of insects | Total number of potatoes | Percent scabby tubers | | | |
|---|---|---|---|---|---|
| | | None | Trace | Moderate | Severe |
| 0 | 92 | 79 | 21 | 0 | 0 |
| 99 | 63 | 66 | 29 | 5 | 0 |
| 198 | 65 | 63 | 29 | 8 | 0 |
| 396 | 50 | 28 | 44 | 26 | 2 |

Figure 1. A combination of potato flea beetle injury (A) and common scab (B) on potato cultivar Norland.


A
B

# CHAPTER III

## PART VI

Scientific Notes

# Distribution of Colorado potato beetle on the potato plant

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# INTRODUCTION

The Colorado potato beetle, Leptinotarsa decemlineata (Say) is an important yield-reducing insect pest on potatoes in Manitoba (Senanayake 1986c). Although the sensitivity of the potato plant to leaf loss at different stages of development is known (Cranshaw and Radcliffe 1980; Shields and Wyman 1984), information concerning the distribution of feeding of this defoliator on the plant is lacking. This information might help to explain yield reductions at low levels of defoliation (Senanayake 1986c).. This laboratory study describes the distribution of Colorado potato beetles on potato plants.

## MATERIALS AND METHODS

The research was performed during 1986 at the University of Manitoba, Winnipeg using Colorado potato beetles collected locally in the fall of 1985. A Colorado potato beetle colony was maintained in an incubator at LD 16:8 and $25^{o}C$. Eggs, larvae and adults were reared on excised potato leaves (cv. Norland) in separate petri dishes (15 cm diameter) lined with moist filter paper.

The distribution of Colorado potato beetles on plants were determined in a growth room under the same environmental conditions. Potato (cv. Norland) seed pieces of 40-55g were planted in pots 30 cm diameter and 24 cm deep. Plants were individually caged one day before the observations were made. Cages were 0.6x0.6m and 0.75m high and were wood-framed and covered with white nylon netting (28 meshes per cm). On opposite sides of each cage there were 15 cm diameter sleeves 0.35m above soil level, to give access. Experiments were carried out when plants were about 50 cm high. The caged plants were exposed to one of three treatments A, B or C. In treatment A, one late larva (third or fourth instar) was placed on each of the top, middle and bottom strata (there were approximately the same number of leaves in each stratum). In treatment B, one adult was placed on the soil near the main stem. Treatment C was similar to treatment A, except that adults were used instead of late larvae. Larvae and adults were allowed to settle for a period of 24 and 1 hr, respectively, before the observations were made. Treatment A was replicated eight times and treatments B and C were replicated four times. The experiment was conducted over a three day period during which hourly records of the position of the insects were made from 9:00 hr to 17:00 hr on each day. Results were analysed using the $\chi^2$ test (Sokal and Rohlf 1981) at the $P \leq 0.05$ significant level.

# RESULTS

During the three day period Colorado potato beetle larvae and adults moved towards the top stratum (Fig. 1). After moving to the top, the larvae confined their feeding to the top stratum. However the adults showed some movement between the top and the middle strata, but always a majority remained in the top stratum. Occasionally the insects were observed around the growing points of the plant.

Comparison of the frequency distribution of counts indicated that the number of larvae (treatment A, $\chi^2 = 60.81$, df = 4) in the top, middle or bottom stratum depended upon the day observed. However, the number of adults (treatment B, $\chi^2 = 4.82$, df = 6, and treatment C, $\chi^2 = 12.02$, df = 6) at each location was the same for all three days sampled.

# DISCUSSION

The study shows that the Colorado potato beetle larvae and adults usually move to or remain in the top stratum compared with middle and bottom strata. Unlike the adults, the larvae in the middle and bottom strata of the plant showed a gradual movement to the top stratum. In the laboratory, larvae were observed at the growing points of the plant less frequently than , in the field (personal observations). Since damage to the top leaves has a greater impact on yield (Cranshaw and Radcliffe 1980; Shields and Wyman 1984), this may be the reason why Colorado potato beetle feeding is more detrimental to the plant than a similar amount of defoliation spread over all portions of the plant as occurs for potato flea beetles (Senanayake 1986d).

## ACKNOWLEDGEMENTS

Special thanks are due to H.M. Morris, Department of Entomology, University of Manitoba, Winnipeg, Manitoba, for providing Colorado potato beetle adults needed for the experiment. Financial assistance was provided by a grant from the Canada/Manitoba Subsidiary Agreement on Value Added Crop Production, by the Manitoba Department of Agriculture and by the Canadian Commonwealth Scholarship and Fellowship Committee.

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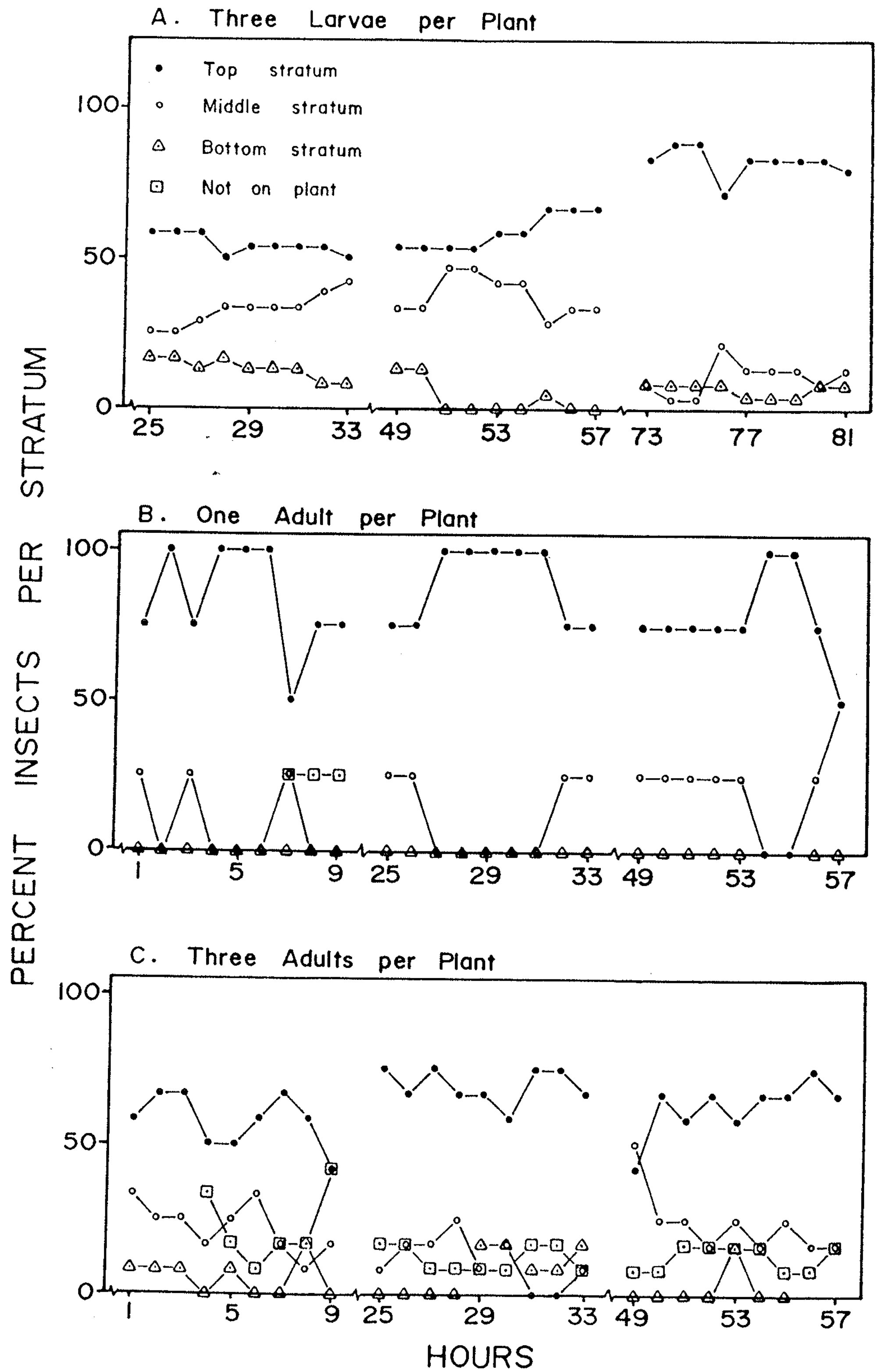
Figure 1. The distribution of Colorado potato beetle larvae (treatment A) and adults (treatments B and C) on top, middle and bottom plant strata for a period of three days in 1986.


A. Three Larvae per Plant
Top stratum
Middle stratum
Bottom stratum
Not on plant
B. One Adult per Plant
C. Three Adults per Plant
PERCENT INSECTS PER STRATUM
HOURS
0
50
100
25
29
33
49
53
57
73
77
81
1
5
9

# CHAPTER III

## PART VII

Scientific Notes

# Effect of spray timing on yield of potato (cv. Norland) in Manitoba

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# INTRODUCTION

Effectiveness of an insect control strategy depends largely on the timing of its application relative to the phenology of the target species. Early applications may miss some insects whereas if the application is too late, injury may already have occurred. Also from the standpoint of insecticide residue and resistance management, it is best to avoid unnecessary insecticide applications (Harris and Svec 1981).

In Manitoba, the major defoliators of potatoes are Colorado potato beetle, *Leptinotarsa decemlineata* (Say) and potato flea beetle, *Epitrix cucumeris* (Harris); of these Colorado potato beetle is the only species of economic importance (Senanayake 1986c, d). Growers apply insectides to control Colorado potato beetles, with little knowledge of the efficacy of such treatments. The purpose of the present study is to determine the appropriateness of the timing of insecticide applications and to identify the strategy that would result in maximum revenue.

# MATERIALS AND METHODS

The experiment was carried out on five isolated plots of potato cv. Norland at the Agriculture Canada Research Station in Morden, Manitoba in the summer of 1984. Each plot consisted of 8 rows 10m long, with 1m spacing between rows and 0.3m between plants within-rows. The plots were located along the margin of a wheat field cv. Benito with each plot separated by at least 50m of wheat. The plots were prepared and treated the same way as the experimental plot (insecticide free control) at Morden (Senanayake 1986a), except for insecticide applications. Insect densities were manipulated by selectively using deltamethrin at 5-7.5g A.I. per ha, thus permitting comparisons of different control strategies and infestations. Fifteen randomly selected plants from each plot were examined each week for Colorado potato beetles and potato flea beetles. The number of plants that were completely defoliated was recorded throughout August. The plots were harvested at the same time as commercial harvesting and the yield compared with that obtained from the experimental plot and from growers' fields (Senanayake 1986c). Only the marketable yield [tubers more than 5.8 cm in diameter (Canada Department of Agriculture 1972)] was considered in the present study. Colorado potato beetle larvae were classified into early larvae (first and second instars) and late larvae (third and fourth instars).

Since insect densities in growers' fields were assessed by sweep-netting, calibration equations (Senanayake 1986a) were used to convert these to estimates equivalent to visual estimates. The calibration equations are:

Colorado potato beetle $Ys = 4.637X$ and $Yv = 0.690X$, potato flea beetle $Ys = 3.025X$ and $Yv = 0.235X$, where $Ys$ = sweep-net estimates, $Yv$ = visual estimates and $X$ = whole plant bag sample estimates.

# RESULTS

Figure 1A-G shows the population curves for Colorado potato beetle and potato flea beetle in growers' fields (Fig. 1A), the five isolated plots (Fig. 1B-F) and the experimental plot (Fig. 1G). Complete defoliation of plants was not observed in treatments A, B and D. However, 50-75% of the plants in treatment C and E were completely defoliated in late-August whereas all plants in treatment F and G were completely defoliated in mid- and early-August, respectively. Table 1 provides the yields for the seven treatments and the cost-benefit analysis.

# DISCUSSION

The importance of timing of application of insecticides to control Colorado potato beetle is well illustrated in the study. Single application of insecticides in late June or early-July before the larval peak (Fig. 1D) required an additional application to control the summer adults (Fig. 1B). The yield for treatment D shows that it is justifiable to control summer adults, when compared with treatments A and B where Colorado potato beetle summer larvae and adults were controlled. The treatments C, E, F and G did not maximize economic returns and they would not be acceptable alternative strategies. These results are similar to that reported by Ferro et al. (1983) on a medium- to early-maturing cultivar "Superior" in Massachusetts where there are two generations of Colorado potato beetle. They obtained highest profits where only first generation (referred to as summer generation in the present study) Colorado potato beetle was controlled and suggested the use of a systemic insecticide (aldicarb) at planting for season-long control of this species.

The relatively low densities of potato flea beetle summer adults in treatment F and G, could be because Colorado potato beetles made plants unsuitable for potato flea beetles by completely defoliating them. In treatment A, B, C, D and E summer adults might have remained within the plot as there was adequate food. Application of insecticide in mid-July when potato flea beetles were dying and the summer generation was still in the soil gave poor control of potato flea beetle. However, a second application of insecticide (treatment A and B) had a considerable impact upon the species. Although potato flea beetles do not usually occur in sufficient density to cause economic damage in Manitoba (Senanayake

1986d), the present study indicates that treatment in late July or early August gives the best control of this species if control is required.

# ACKNOWLEDGEMENTS

Special thanks are due to B. Chubey, B. Rex and H. Wolfe, Agriculture Canada Research Station, and R. Warkentin, Kroeker Farms, for their generous assistance. Financial assistance was provided by a grant from the Canada/Manitoba Subsidiary Agreement on Value Added Crop Production, by the Manitoba Department of Agriculture and by the Canadian Commonwealth Scholarship and Fellowship Committee.

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Senanayake, D.G. 1986d. Economic injury level for the potato flea beetle (Coleoptera:Chrysomelidae) on potato and a comparison of plant response to defoliators. Chapter III, Part IV of these studies.

Table 1. Insecticide application dates, mean yield, mean total revenue and net revenue per ha for potato (cv. Norland) defoliation treatments at Morden, Manitoba, 1984

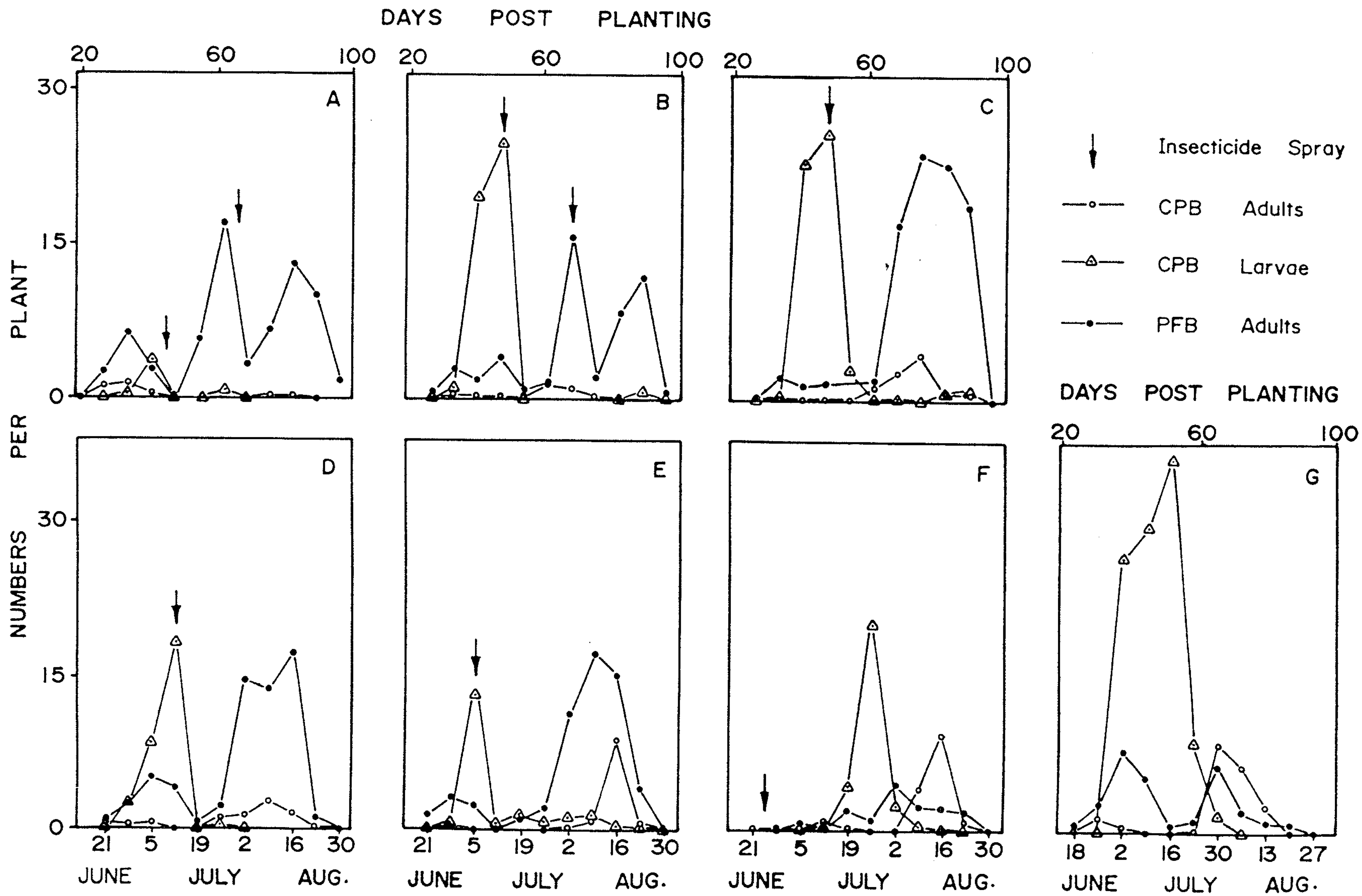
| Treatment | | Insecticide[a] application date: 25 June | 5 July | 9 July or 12 July | 30 July or 2 August | Yield (metric tons/ha) | Total revenue ($/ha)[b] | Control costs ($/ha)[c] | Net revenue ($/ha) |
|---|---|---|---|---|---|---|---|---|---|
| Growers' | A | - | - | Ca | En | 24.0 | 5286 | 37 | 5249 |
| Isolated plots | B | - | - | De | De | 19.5 | 4277 | 34 | 4243 |
| | C | - | - | de | - | 7.6 | 1663 | 13 | 1650 |
| | D | - | - | De | - | 12.5 | 2732 | 17 | 2715 |
| | E | - | De | - | - | 8.9 | 1960 | 17 | 1943 |
| | F | De | - | - | - | 9.5 | 2079 | 17 | 2062 |
| Control | G | No insecticides applied | | | | 3.9 | 832 | - | 832 |

[a]Insecticides are: Ca = carbofuran, 360g A.I./ha; En = endosulfan, 652g A.I./ha; de = deltamethrin, 5.0g A.I./ha; De = deltamethrin, 7.5g A.I./ha.

[b]Value is based on average of $220/metric ton for marketable potatoes.

[c]Includes cost of insecticides (carbofuran $12.34/ha; endosulfan $12.23/ha; deltamethrin $10.91/ha) and operational cost ($6.00/ha).

Figure 1. Mean number of Colorado potato beetle (CPB) larvae and adults, and potato flea beetles (PFB) for treatments A-G at Morden, Manitoba, 1984.



DAYS POST PLANTING
20
60
100
30
15
0
A
B
C
D
E
F
G
PLANT
PER
NUMBERS
Insecticide Spray
CPB Adults
CPB Larvae
PFB Adults
21 5 19 2 16 30
JUNE JULY AUG.
18 2 16 30 13 27

# CHAPTER IV

## GENERAL DISCUSSION

Colorado potato beetle is the most destructive insect species on foliage of potato in Manitoba. Small populations of overwintered adults colonize the fields in late June around the time that potatoes are emerging. The larvae feed upon the plants in July and cause extensive defoliation. If larvae are not controlled adults continue feeding, resulting in complete defoliation by early August when rapid tuber bulking normally occurs (Senanayake 1986b). Colorado potato beetles' voracious feeding habit (Tamaki and Butt 1978; Ferro et al. 1985), high reproductive capacity (Peferoen et al. 1981) and dispersal ability (de Wilde and Hsiao 1981) together may be responsible for the destructiveness of the species. In the absence of control operations, the early season leaf-chewing herbivory by Colorado potato beetles affects population dynamics of the late-feeding, leaf-chewing potato flea beetles and sap sucking potato leafhoppers and aphids in Manitoba.

The estimated economic injury level (EIL) for Colorado potato beetle under Manitoba growing conditions ranged from one larvae per seven plants to one larvae per plant (Senanayake 1986c) which appears to be low. This could be because in the present study the season-long nature of insect plant interaction was investigated whereas in most of the previous studies (Cranshaw and Radcliffe 1980; Hare 1980b; Shields and Wyman 1984) defoliation was restricted to discrete periods. Although plants might have a potential to compensate for some damage at a particular stage of growth, it appears that plants are less able to compensate when defoliation continues.

Cultivar susceptibility also affects the EIL. When exposed to similar growing conditions and Colorado potato beetle densities, the early-maturing cultivar Norland is found to be much more responsive to insect injury than the late-maturing cultivar Russet Burbank (Lactin, unpublished data). This could be attributed to the differences in size of the plant canopy. The Russet Burbank plant is about four times larger than a Norland plant, therefore the former has more reserves and potential to compensate for insect injury. Whether physiological differences in cultivars also contribute to the different plant responses is not clear.

Although the EIL is based upon injury caused by one generation of Colorado potato beetle, it could also be utilized in regions where late generations of Colorado potato beetle are relatively unimportant. For example, in Connecticut (Hare 1980b) and Massachusetts (Ferro et al. 1983) the early maturing cultivars are insensitive to leaf removal by second generation Colorado potato beetle as tubers were nearly full-sized before defoliation occurred.

In small potato fields in Manitoba (about 100x100m) the EIL for Colorado potato beetle is exceeded throughout the field, whereas in large fields the EIL is exceeded only at the field margins (up to 50m from the edge of the field) (Morris, unpublished data). Beyond the field margins the insect densities are well below the EIL, therefore no control measures are necessary. Perhaps the EILs can be utilized to reduce the amount of insecticide use in large fields by restricting the application to the field margins.

Next to Colorado potato beetle, potato flea beetle is the most important defoliating insect pest on potato in Manitoba. The population pattern of this species has some similarity to Colorado potato beetle.

Small numbers of overwintered adults move into the field in late June and lay eggs in the soil, larvae feed on the root system and pupate in the soil; summer adults emerge from soil and the population peaks in August. Although adults feeding on foliage result in a loss of photosynthetic area, there was no significant reduction in yield at densities observed in the 1983-1985 growing seasons (Senanayake 1986d). In 1985, where the potato flea beetle density was highest of the three years, the insect injury was lower than the EIL and did not warrant control measures. However, it is useful to estimate the potato flea beetle injury because injury may exceed the estimated EIL. The lower response of the EIL of potato flea beetle to changes in control costs and expected yields compared to that of Colorado potato beetle is due to the different plant responses to insect injury.

Although potato flea beetle larval injury on tubers is not of economic importance, its effect on scab disease could result in down-grading of tubers. On Norland, which is moderately susceptible to scab, it is unlikely that scab induction due to potato flea beetle larvae could cause an economic loss. However on a more susceptible cultivar the relationship between potato flea beetle larvae and scab could be more significant and may have to be considered in EIL studies. To prevent the scab component of the potato flea beetle larval injury a new control strategy aimed at either adults that lay eggs in early June or larvae should be devised.

Although there are several integrated pest management strategies known for Colorado potato beetle control (Lashomb and Casagrande 1981), insecticide application has been the major control measure used in North America (Forgash 1985). It is common for growers' to start treatments at the first appearance of beetles and continue on a prearranged schedule. Such a control practice is detrimental as it may result in a greater preponderance of resistant individuals in the overwintering population (Hare 1980a; Harris and Svec 1981). As the number of beetles feeding on wild host plants are few, there is little immigration of susceptible individuals into populations in the treated fields in which resistance is developing. Additionally, on Long Island, New York, pesticides used in potato production (e.g. aldicarb, carbofuran and oxamyl) have contaminated groundwater and are no longer registered for use (Wright 1984). Very few attempts have been made to introduce biological control agents to reduce the amount of insecticides used because of the problems associated with rearing such species (Tamaki et al. 1983b; Schroder and Athanas 1985). The native parasitoids and predators of Colorado potato beetle in North America (Cole 1951; Radcliffe 1982), are relatively ineffective in controlling this species in the field (Harcourt 1971; Tamaki et al. 1983a). Although cultural practices such as crop rotation provide a reduction in number of overwintered adults, its effect is not season-long (Wright 1984). Even low initial densities of the species in rotated fields are able to produce damaging summer populations. Perhaps the most desirable solution to the increasing problem with chemical control and persistant crop losses is the experimentally determined EILs that are provided in the present study. The EILS will help the more rational use of insecticides and also will be useful in evaluating the performance of a control program. In situations where there is no time delay in control operations, e.g. insecticide application, EIL is equivalent to ET, and therefore is of value in maling decisions about whether or not an insecticide should be applied. The injury to the plant that can occur prior to control has little impact on yield, because yields are little affected by insect defoliation early in the season (Hare 1980b).

The EIL for Colorado potato beetle will provide the Norland growers with the basis for making economically sound decisions about the control of the species in field margins or areas where it is really needed. For potato flea beetle, this is the first study of the economic impact of the species on potato. The information provided will prevent unnecessary late season insecticide applications to control the species. Needless to say, these EILs will reduce the insecticide load on the environment and possibly slow or prevent the development of resistance to insecticides by Colorado potato beetle and potato flea beetle in Manitoba, and therefore will be a useful tool in the potato pest management program.

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