A STUDY OF ROOT MAGGOTS INFESTING CANOLA IN THE PEACE RIVER REGION OF ALBERTA

by

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A Study of Root Maggots Infesting Canola In

The Peace River Region of Alberta

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Abstract

Root maggots (Diptera: Anthomyiidae: *Delia* spp.) infest canola, an oilseed crop valued at $100 million in the Peace River Region of Alberta. Studies were conducted during the summer of 1990 to determine the *Delia* species present in a canola planting and whether canola cultivar, trap type and color preferences existed.

Delia species taken were similar to those found in other areas of Alberta. Two adult flights of *D. radicum*, *D. floralis* and *D. planipalpis* were taken in pan traps over one growing season. These three species appear to be codominant in the Peace River Region. Compared with known degree-day information, trap captures indicate that a summer generation of adult *D. radicum*, *D. floralis* and *D. planipalpis* exists, but that not enough degree-days are available for completion of two full generations. *D. platura* populations had several peaks in early and mid summer, probably representing three adult flights.

Four vitavax-treated *B. rapa* cultivars, 'Tobin', 'Colt', 'Parkland' and 'Horizon', along with one vitavax-treated *B. napus* cultivar 'Westar' and one untreated 'Tobin' plot were used to evaluate the preferences of *Delia* species to these canola cultivars. *D. radicum* and *D. floralis* were not trapped in significantly higher numbers in any of the varieties tested. Cultivar preferences were observed in *D. planipalpis* and *D. platura* at certain times during the growing season. Levels of *D. planipalpis* males were taken in significantly greater numbers in treated 'Tobin' than in 'Westar', but not until the August

flight period. Significantly more female *D. planipalpis* were taken on August 17 in untreated 'Tobin' than in 'Tobin', 'Westar', 'Colt' or 'Parkland' plots treated with vitavax seed treatment. Significantly higher levels of *D. platura* females were taken in treated 'Tobin' than in untreated 'Tobin' plots on July 20.

U.V. reflecting white, white, yellow, blue and green colored sticky traps were evaluated for *Delia* spp. preferences. Color preferences were recorded in three of the *Delia* species. Blue and white were found to attract *D. radicum*, *D. floralis,* and *D. platura*. Yellow was also found to be a preferred color for *D. radicum* and *D. floralis,* with attraction by *D. planipalpis* being uncertain from the data. Although yellow was not significantly preferred by *D. platura*, very high numbers of both males and females were still captured on yellow traps. In a trap comparison study, adult *Delia* spp. preferences for yellow pan or yellow sticky traps were found to exist at various periods throughout the growing season. The study showed that pan traps used alone could miss certain species at certain times during the growing season. Pan traps could be abandoned in favor of sticky traps for routine monitoring, except where intact specimens for positive identification are desirable. Sticky traps captured significantly more *Delia* spp. adults than pan traps throughout the growing season, except late in August, when pan traps were better for some species.

Dedication

To my children, who give me faith and a great deal of happiness.

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I would like to thank Dr. R.S. Vernon who conferred with, guided, and encouraged me during this work, and the members of my supervisory committee for reviewing my thesis and for the valuable comments they made.

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CHAPTER 1

ROOT MAGGOTS INFESTING CANOLA IN THE PEACE RIVER REGION OF ALBERTA:

INTRODUCTION AND BACKGROUND:

Root maggots (Diptera: Anthomyiidae: *Delia* spp.) are serious pests of cruciferous crops in Europe and North America (Caesar, 1922). The family *Cruciferae*, with about 3,000 species, is found primarily in the northern hemisphere. *Brassicae* species have been cultivated since pre-historic times for their edible parts.

Varieties of canola grown in Canada belong to either *Brassica napus* L. or *B. rapa* L. (previously *B. campestris* L.). *B. rapa* is native to Europe, central Asia, and the Near East and was probably domesticated as a source of oil in central Asia or northwestern India. *B. napus* is not found in wild populations and was probably domesticated in southern Europe. The two species differ morphologically and in chemical composition; they also grow at different rates. These differences complicate the study of pests associated with canola (Lamb, 1989). Within a species, cultivated crops have been developed for different purposes. For example, varieties of *B. rapa* with an enlarged fleshy root provided the turnip, whereas the headed form produced the Chinese cabbage. The same species developed for oilseed production became canola (Anonymous, 1984).

Canola is grown on more than 2.8 million ha (7 million acres) in western Canada (Anonymous, 1992b). Injury by root maggots occurs when the larvae tunnel through and around the roots during feeding. Further reductions in yield occur if root rot fungi invade the damaged root tissue (Griffiths, 1986a). In the northern areas of Alberta, especially the northwestern region, canola has sustained more serious injury from root maggots than it has in more southern regions (Liu, 1984).

SOILS

The Peace River Region in northern Alberta, an area of prairies and parkland within a boreal forest, has primarily dark-grey and dark-grey wooded solonetzic soils. These soils developed under a dry-subhumid to subhumid climate, under a fairly continuous tree cover (Odynsky et al, 1956). The solonetzic soils are associated with a vegetative cover of grasses and forbes.

Many of the parklands are on soils that have developed on a heavy, somewhat saline parent material, and they are distinguished by a clay pan relatively near the surface. Such a clay pan might be unfavorable for good tree growth and, perhaps as a result, trees did not become well established. Apparently trees did not become established until solodization was well underway (Agriculture Canada, 1987).

CLIMATE

The average annual rainfall in the Peace River Region varies between 400 and 480mm, with relatively warm summer temperatures (up to 30°C in the afternoon and evening temperatures of around 10°C). The growing season is relatively short (less than 160 days above 5°C), but the agricultural potential is improved substantially by the long summer daylight (up to 17h 26min from sunrise-sunset). Winters are long and cold (Anonymous, 1990a).

The length of the growing season and the moisture received are critical in determining the types of crops that can be grown. The duration of the frost-free period is also very important in determining the risk in growing certain crops and the range of crops that can be grown.

In Grande Prairie and the surrounding area total precipitation between May 1 and August 31 averaged around 250mm during the period 1951-1980. There were about 1300 total annual degree-days above 5°C during the same period. The frost-free period may vary from 75 to 144 days (Anonymous, 1990a).

CROPS

A variety of crops can be grown and productivity is generally good. Cereal crops such as wheat, barley, oats, and canola are the dominant annuals. Perennial forages, grown for feed and seed, are common, comprising 14% of total farm land (Anonymous, 1992b).

PRODUCTION OF CANOLA:

Canola (historically termed rapeseed) is the agricultural analog of soybeans, although they belong to different plant families. Both crops produce seeds which are high in vegetable oil and high-protein meal, and they compete on international markets. Both are grown over large areas of North America, Europe, and other regions of the world. The oilseed *Brassicae* crops perform better than soybeans in cool, short-season climates but poorly at high temperatures (Lamb, 1989).

Canadian rapeseed production resulted from the critical shortage of oil that followed the World War II blockade of European and Asian sources. The oil was urgently needed as a lubricant for the rapidly increasing number of marine engines. Canola seed contains more than 40 percent oil when crushed (Anonymous, 1984).

Oilseed *Brassicae* plants produce glucosinolates, a group of more than 70 compounds characteristic of the *Cruciferae* and a few other plant families. These compounds or their fission products may function in four ways: 1) as anti fungal agents; 2) as feeding deterrents; 3) as toxins for some insect herbivores; and 4) as antifeedants or toxins for some wild vertebrate herbivores and some farm animals (Lamb, 1989). As early as 1956, experts questioned the nutritional benefits of rapeseed oil, especially because of the high eicosenoic and erucic fatty acid contents (Anonymous, 1984).

Rapeseed meal is an excellent source of protein with a favorable balance of amino acids; however, the use of rapeseed meal in feed rations has been limited by its glucosinolate content, which led to palatability and nutritional problems when fed to livestock and poultry. Plant breeders responded quickly by selecting rapeseed strains with low eicosenic and erucic acid content, by 1960 in *B. napus*, and 1964 in *B. rapa* (Anonymous, 1984). These desirable characteristics were then bred into suitable varieties. Newly developed rapeseed varieties became known as "double low" varieties. The term canola is now a registered trademark with the Canola Council of Canada. It is applied to modern rapeseed varieties known as "double low" having 5 % or less erucic acid content and less than 30 micro moles of glucosinolates/gram of oil-free meal.

Polish canola cultivars, *B. rapa* L., are the most commonly grown in the Peace River Region, largely because of their early maturity. They comprise about 75% of the total canola acreage, and Argentine canola, *Brassicae napus* L., accounts for the remainder. The latter are higher yielding but later maturing.

In the Peace River Region close to 400,000 ha (1,000,000 acres) of canola are grown, and this area is increasing yearly. In 1991, the Canadian Wheat Board reported that 337,590 ha (840,983 acres), or 25.57% of the total seeded area in the Peace River Region, was planted to canola (Anonymous, 1992b).

ROOT MAGGOTS INFESTING CANOLA:

Brooks (1951) identified *Delia radicum* (*Hylemya brassicae* (Bouche), *D. floralis* (*H. crucifera* Huck.), and *D. planipalpis* (*H. planipalpis* (Stein)) as phytophagous species causing extensive root damage to cruciferous plants. *D. platura* (*H. cilicrura* (Rond)) and *D. florilega* (*H. trichodactyla* (Rond)) were listed as phytophagous or saprophagous species but were generally only present and caused damage in association with members of any of the other three species above. All five species are listed as widespread and important pests.

After the establishment of canola as a major field crop in Alberta in the 1970's, there were reports that root maggots were responsible for damage (Griffiths, 1985). The main species responsible for damage have been the cabbage maggot, *D. radicum* L., although flies of *D. planipalpis* (Stein), *D. platura* (Meig.), and *D. florilega* (Zett.) have been reared from infested roots (Liu and Butts, 1982).

Based on samples from canola fields, Griffiths (1986b) mapped the relative abundance of root maggot adults of *D. radicum* (L.) and *D. floralis* in Alberta. He found *D. radicum* to be the most abundant species in the North West Region, whereas *D. floralis* was most abundant throughout the North East and the Peace River Regions (Figure 1).

The cabbage maggot, *D. radicum*

D. radicum is the major root maggot, which infests all forms of cultivated *Brassicae*, such as cabbage, cauliflower, broccoli, kale, kohlrabi, Brussels sprouts, Chinese cabbage, collards, mustard, rapeseed, turnip, swede, and rutabaga, as well as radish (*Raphanus*), horseradish (*Armoracia*) and stock (*Matthiola*) (Griffiths, 1991b). The earliest accounts of the cabbage maggot were recorded from Europe long ago, as an important pest of cabbage and closely related plants. This insect first reached the United States and was initially reported in Canada around 1855 (Caesar, 1922). It was recorded from Saskatchewan in 1952 and from Manitoba in 1958 (Beirne, 1971).

Ovipositing females are solitary and usually deposit eggs in small batches near the root collar or on the axils of lower leaves. First-instar larvae move down the tap root, penetrate the periderm, and feed on the parenchyma tissue of secondary phloem. Larger second-and third-instar larvae aggregate on the root surface, creating progressively wider feeding channels along the root length. Injury is primarily confined to phloem, periderm, and xylem parenchyma tissues, but can include the proximal region of the lateral root system in proportion to the level of attack (McDonald, 1985).

Soil characteristics, moisture, cultural practices and natural enemies influence population densities. In general, infestations tend to be light on heavy soils and heavy on light or 'maggot-susceptible' soils. Infestations tend to be high in wet periods and low in dry ones (Beirne, 1971).

The turnip maggot, *D. floralis*

D. floralis is well-known as a root maggot which attacks cultivated *Brassicae* and other crucifers in Northern Europe (Griffiths, 1991b). The species has adapted to the expansion of rapeseed cultivation in western Canada, and canola varieties are now important hosts. The distribution of this species is much more northerly than *D. radicum*. It has been collected at many northern localities across Canada and Alaska, but has not been reported from the contiguous United States (Griffiths, 1986b).

The radish root maggot, *D. planipalpis*

D. planipalpis has been recorded as a pest of Chinese cabbage, turnip, cabbage, cauliflower, rutabaga, mustard, Brussels sprouts, and radish (Griffiths, 1991b). A heavy root infestation was documented on rapeseed canola at Berwyn in the Peace River Region of Alberta by Griffiths (1986c). This species is believed native to western North America, occurring at northern localities remote from cultivation or agricultural regions. In the Palaearctic Regions of Europe and eastern Asia it is widespread (Griffiths, 1991b).

The seed corn maggot, *D. platura* and the bean seed maggot, *D. florilega*

D. platura and *D. florilega* are two species that occupy similar ranges. *D. platura*, the most widespread and abundant species of *Delia* worldwide, occurs in all geographic regions except Antarctica. Beirne (1971) confuses *D. florilega* with *D. floralis*; information provided in Beirne's review is difficult to separate, as pointed out by Griffiths (1993). The larvae of *D. platura* commonly occur as "seed maggots" on cultivated land, often together with larvae of *D. florilega*, in northern parts of their range. In central Canada, larvae of *D. platura* are normally more abundant than those of *D. florilega*. This was reported to be the opposite in the early 1960's because *D. florilega* had developed resistance to the cyclodiene insecticides then in use (Griffiths, 1993).

The range of food used by larvae of *D. platura* is much wider than that any other species of *Delia* and includes animal material (especially grasshopper egg-pods), fecal, and plant material. The larvae are generally secondary feeders, following primary invasion by larvae of *D. radicum* or *D. floralis* (Griffiths, 1993). However, primary infestations have been seen in leguminous crops such as beans (*Phaseolus vulgaris* L.) during seed germination and in solanaceous crops, such as potatoes (*Solanum tuberosum* L.) and tobacco (*Nicotiana tabacum* L.), in Canada and the NE United States. Other crops reported to be damaged include cereals, spinach, sugar beets, cotton, lettuce, artichoke and carrots. A detailed list is provided by Griffiths (1993).

ECONOMIC LOSSES CAUSED BY ROOT MAGGOTS:

Studies involving *B. rapa* cv 'Tobin' at the University of Alberta showed that plants severely damaged by root maggots may have their potential yields reduced by 50% (Griffiths, 1991a). Because canola is a major crop, worth over $100 million to the Peace River Region (Anonymous, 1990b), any yield loss over 1% due to root maggots would be of considerable economic concern.

The conversion of root maggot feeding to economic damage on canola in the field is often difficult because maggot damage is usually associated with several endemic root rot organisms. Root rot of canola is a fungal disease complex caused by combinations of *Rhizoctonia*, *Pythium*, and *Fusarium* species. These fungi survive in the soil on decaying organic matter and infect seedlings and growing plants under ideal conditions (Anonymous, 1990b).

Until recently the importance of insect and disease organisms as primary or secondary pests of canola had not been determined. However, Griffiths (1985) found that foot rot, involving *Fusarium* spp., occurred in all plants having maggot-damage, but not in plants without it. Four species of *Fusarium* were identified from cultures grown from field samples. These were *F. avenaceum* (Corda ex Fr.) Sacc., *F. sambucinum* Fuckel, *F. tricinctum* (Corda) Sacc., and *F. acuminatum* Ellis & Everh. (Griffiths, 1991b). All plants in plots without maggot damage had green stems and clean white roots at harvest. These findings suggest that feeding by root maggots causes primary damage, facilitating the secondary establishment of root rot organisms. The relationship between root maggots and root rot, therefore, should be considered when developing strategies to reduce the impact of these pest organisms in canola.

CONTROL OF ROOT MAGGOTS IN CANOLA:

The approaches to control of root maggots in most areas include: 1) cultural, 2) chemical, 3) natural, and 4) a combination of the above, integrated pest management (IPM).

1) *Cultural controls* have had some success in various cruciferous crops. Beirne (1971) reported *D. radicum* infestations were heaviest when early and late crops were planted in the same field. Late plantings in sandy soils suffer less damage. Strains of turnips resistant to *D. radicum* were susceptible to *D. platura*, and vise versa. In plantings of cabbage, cauliflower, Brussels sprouts and swede, some success was indicated with higher density plantings. Maxwell (1990) suggested mixing crop species in stands or mixing

resistant and susceptible varieties to provide pest management opportunities.

Vernon (R.S. Vernon, personal communication) has had some success with exclusion, using fine mesh fences in rutabaga plots. In canola plantings, Dosdall (1992) has shown that tillage after harvest reduced the ability of the pupae to overwinter. An evaluation of canola species and cultivars for susceptibility to infestation by root maggots has shown preferences for egg laying (L. Dosdall, personal communication). In northern areas, cultural controls in canola by changing crop rotation or sowing dates do not have much promise (Griffiths, 1985).

2) *Chemical control* of *Delia* spp. is available for the many crop hosts that *Delia* spp. infest (Read, 1970; Stewart, 1955; Yaman, 1960); however, for canola, there has been little research. Insecticidal seed treatments or seed drill applications of granular insecticides are currently used in the prairie provinces to protect germinating seeds from the crucifer flea beetle (*Phyllotreta cruciferae* (Goeze) (Anonymous, 1992a). These chemicals, however, are not persistent enough to protect the plants later in the season when root maggot infestation typically occurs. Applying insecticides to control adult *Delia spp.* in canola plantings should be considered only after careful field trials designed to measure the effects on target and non-target organisms (Griffiths, 1985). In the 1992 "Guide to Crop Protection with Chemicals", no treatments are listed for control of root maggots on canola (Anonymous, 1992a), although studies on chemical seed treatments in canola are ongoing (Griffiths, 1992). Yield increases

were achieved in *B. rapa* varieties (9.4% and 12.1% at two locations in northern Alberta) and in *B. napus* varieties (17.8% at one location in northern Alberta) with Counter® (terbufos), an organophosphate, and Amaze® (isofenphos), a carbamate.

3) *Natural controls.* Two fungal pathogens of *Diptera* occur commonly in North America, *Entomophthora muscae* (Cohn) Fresenius and *Strongwellsea castrans* Batko & Weiser (Entomophthoraceae) both of which attack *D. radicum* naturally in northern Alberta. Under natural conditions, S. *castrans* becomes prevalent in July. If it could be artificially introduced earlier, it appears to have more potential than *E. muscae*, which has had limited field success even under ideal conditions (Griffiths, 1985).

There are various natural insect enemies of *D. radicum*, including at least seven species of parasites and twelve predators (Beirne, 1971). Griffiths (1985) identified many insects caught in field emergence, bowl and pitfall traps. There were at least nine species of *Amara* (Carabidae), along with *Agonum placidum* Say (Carabidae), *Pterostichus* (Carabidae), *Bembidion* (Carabidae), and three species of the staphylinid genus *Philonthus*. All of these probably can feed on other insect prey with the exception of the staphylinid *Aleochara*, also caught in traps, which feeds on the immature stages of calyptrate flies.

Beirne (1971) lists *Aleochara* as both a parasite and a voracious predator. A pair can kill an average of 2400 eggs or first instar *Delia* spp. larvae, or about 250 third instar larvae, and the female may produce sufficient offspring to parasitize 230 puparia. However, this species does not eliminate populations or provide economic control primarily because its life-cycle and that of *D. radicum* are not synchronized; the staphylinids do not emerge until the first generation of maggots are nearly mature and have already done most of their damage.

Griffiths (1985) found *Aleochara bilineata* Gyllenhal in traps in mid-June, and they remained abundant through July. A parasitoid wasp, found in low numbers in puparia of *D. radicum*, was *Trybliographa rapae* (Westwood) (Hymenoptera: Cynipidae). A single specimen of another parasitoid, *Phygadeuon* spp. (Hymenoptera: Ichneumonidae) was also recovered.

4) *Integrated Pest Management* (IPM) programs that may involve chemical, cultural, and biological controls will need relevant population evaluations and predictions for the areas of use. This would mean knowing the species composition and their relative abundance in space, time and in the various crops. Future work in pest management will call for information on trapping methods, species-preferred trap colors, numbers of generations, development times, and information on host cultivars.

RESEARCH OBJECTIVES:

Developing sound integrated pest management of any crop needs considerable knowledge of the pest organisms and the ecosystem. In the Peace River Region little is at present known about the composition and relative importance of the various *Delia* spp. known to attack canola. The present knowledge is limited to a small number of short-term studies conducted between 1982-1986 (Liu and Butts, 1982; Liu, 1984; Griffiths, 1985, 1986a, 1986b, 1986c). Since the relative numbers of *Delia* species will vary within and between growing seasons in particular areas, early conclusions about species dominance, based on short-term trapping studies, may not be valid. The first step toward developing a successful management program in the Peace River Region would therefore be to study the diversity of root maggot species present in canola fields throughout one or more entire growing seasons.

The development of a reliable monitoring program for the key pests of a crop is the important requirement for any IPM program. Monitoring programs, often called for when conducting basic studies of the ecology and life history of insect pests, are also commonly used to determine the need for and results of control measures in ongoing IPM programs (Coaker, 1969; Finch and Skinner, 1982; Vernon et al, 1989).

Traps of various designs have been developed to monitor populations of several *Delia* species: 1) Yellow water pan traps and yellow sticky traps have been used to monitor adult populations of *D. radicum* (Finch and Ackley, 1977; Griffiths, 1985, 1986a, 1986b, 1986c, etc.); and 2) White sticky traps have been used to monitor adult populations of *D. antiqua* and *D. platura* (Vernon and Borden, 1983; Vernon, 1986; Vernon et al, 1989).

Although yellow water pan traps will collect populations of *D. floralis* and *D. planipalpis* (Griffiths, 1986b), there have been no studies to determine the relative color preferences of these species, nor have colored sticky traps been evaluated as potential monitoring tools in canola. Without knowledge of the relative attractiveness of colors or trapping devices to the various *Delia* species in canola, the species composition of populations (qualitative or quantitative) cannot at present be determined with confidence.

The objective of my research was threefold: 1) to determine the potential number of generations of key *Delia* species in the Peace River Region, 2) to determine if specific *Delia* species have a preference for certain cultivars of canola, and 3) to evaluate trapping methods and trap color preferences as they exist in key *Delia* species in the Peace River Region.

The significance of these studies towards developing integrated pest management strategies for canola in the Peace River Region are discussed in a concluding chapter.

CHAPTER 2

DIVERSITY AND ABUNDANCE OF ADULT *DELIA* SPP. IN CANOLA:

Liu and Butts (1982), Liu (1984), Griffiths (1985, 1986a, 1986b, 1986c,), and Steiner (1986) investigated the occurrence of root maggots infesting *Cruciferae* in central and north central Alberta. Species which were identified were *Delia radicum* (L.), *D. floralis* (Fallen), *D. planipalpis* (Stein), *D. platura* (Meigen) and *D. florilega* (Zetterstedt). Infestations of canola surveyed by Liu and Butts (1982), identified *Delia* spp. by larvae collected and matured from a canola field near Smokey Lake, in the North East Region, 90 km. north-east of Edmonton (Figure 1).

DISTRIBUTION AND LIFE CYCLES:

D. radicum

A detailed map of the Nearctic distribution of *D. radicum* in Griffiths (1991b), places this species across much of central Alberta, excluding the arid south-east. Not all of the Peace River Region is included.

Adult *D. radicum* generally emerge from overwintering puparia between mid-May and mid-June (Griffiths, 1985). The flies gather in sheltered areas and are commonly found along the grassy margins of canola fields. Adults live from two to five weeks. Following an undetermined pre-oviposition period, gravid females disperse into the canola fields. The eggs are laid singly or in small batches at the root collar or on the axils of lower leaves. In field observations at

Vegreville and Morinville (near Edmonton) most plants had five or fewer eggs, although up to 15 eggs per plant were found (McDonald, 1985).

Oviposition on canola begins at the time when the crop starts to bolt, about mid-June (Griffiths, 1985). Dosdall (personal communication) found the egg laying peak of *Delia* spp. on June 19, 1989 in the Vegreville area. Work by Steiner (1986), on oviposition by *D. radicum* on rutabaga in the Edmonton area, recorded a peak egg laying period from June 23 to July 3. A second, higher peak of oviposition, occurred around September 2. Steiner, therefore, found *D. radicum* to be bivoltine in rutabaga crops in the same area that Griffiths (1985) reported them to be univoltine on canola.

In Alberta, larvae of *D. radicum* inflict root damage on canola in July, by the end of which most have pupated. Most puparia overwinter, and adults of the relatively insignificant second generation do not oviposit on canola (McDonald and Sears, 1991).

D. floralis

D. floralis, the turnip maggot, has a nearctic distribution similar to that of *D. radicum*, but is less abundant in the moist North West Region around Edmonton (Griffiths, 1991b). Griffiths (1986b) found *D. floralis* to be the predominant species in the North East and Peace River Regions (Figure 1). Liu and Butts (1982) did not find *D. floralis* in their collection of flies from the Smokey Lake area and, hence, the species is not listed in Liu's (1984) damage assessments.

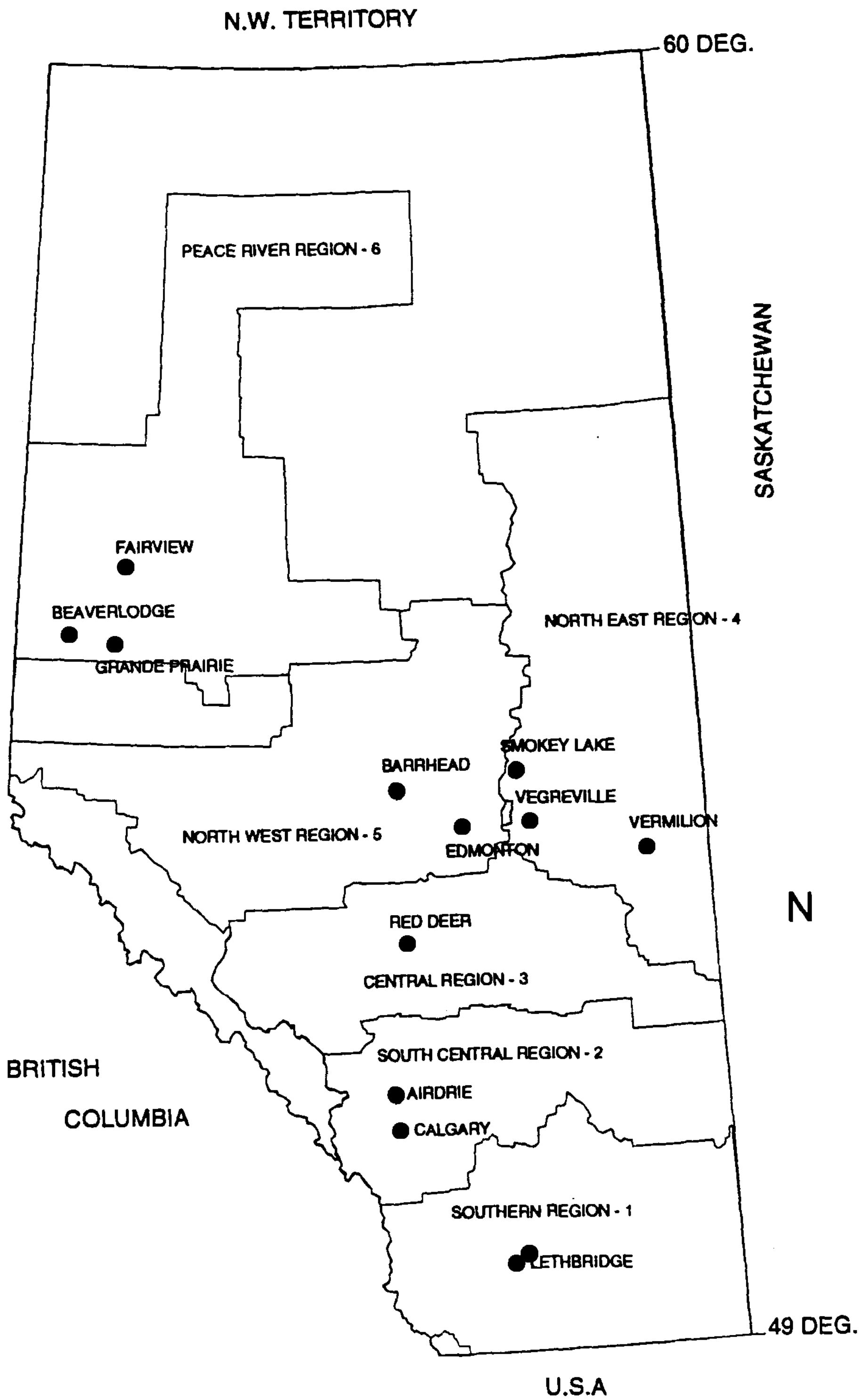


Figure 1. Map of Alberta showing Alberta Agriculture Regional Divisions and major urban centers.

Griffiths (1986c) found the dominant species in canola fields throughout the Peace River Region to be *D. floralis*. He quotes Strickland (1938) "in 1929 this fly destroyed large areas of stinkweed (*Thlaspi arvense* L.) in the Peace River District". Stinkweed is an alternate host for some species of *Delia*. It is the most common weed in the Peace River Region, found in 85% of fields surveyed, in numbers up to 1048/m^2 (Maurice et al, 1990).

The adult phenology of *D. floralis*, studied in the Edmonton area, was similar to that of *D. radicum*, where both were univoltine (Griffiths, 1986c). *D. floralis* first appeared in samples collected in bowl and sticky traps, June 4-7, about three weeks later than the first appearance of *D. radicum*, which were first collected on May 11-14, 1982.

D. planipalpis

The distribution of the radish root maggot, *D. planipalpis*, shows individual collection sites within Alberta but no defined range (Griffiths, 1991b). Griffiths notes "this species is surely native to Western North America, since it occurs at northern localities remote from cultivation as well as in agricultural regions."

D. planipalpis is univoltine in the more northern areas of cultivation in Alberta (Griffiths, 1991b). He notes that infestations occur in early sown crops in these northern areas.

At Brandon, Manitoba, Kelleher (1958) reported a second generation of adults which began oviposition in mid-July or early August. He thought it probable that there are three generations per year in total. Kelleher noted that the overwintering puparia were formed after the third week of August in that year. The peak of second generation fly emergence had been observed during the first week of August.

D. platura

The seed corn maggot, *D. platura*, is the world's most widespread and abundant species of *Delia*, occurring in all zoogeographic regions except Antarctica (Griffiths, 1993). It is reported to have several generations per year. It has worldwide distribution due to its ability to adapt to local climate conditions. In northeastern parts of the Nearctic range, there are three or four generations a year.

Infestations of seed corn maggot larvae on roots of non-seedling cruciferous crops are generally secondary, following primary invasion by larvae of *D. radicum* or *D. floralis* (Griffiths, 1993). However, Nair and McEwen (1973) demonstrated that primary infestations can occur on radish (*Raphanus sativus* L.) roots. Primary invasions are also reported on such crops as beans (*Phaseolus vulgaris* L.) during seed germination (Miller and McClanahan, 1960), on corn (Funderburk et al, 1984), on potatoes (*Solanum tuberosum* L.) and tobacco (*Nicotiana tabacum* L.) (Griffiths, 1993).

DEVELOPMENTAL REQUIREMENTS:

Degree-day (also termed day-degree or DD) accumulations are heat unit summations used for predicting insect development. In developing degree-day models, a threshold temperature must be determined, below which development ceases and above which it is initiated. When Arnold's (1960) correction table is used, the computed degree-days have been called thermal units (TUs).

Developmental predictions using degree-day models are used to improve the timing of chemical, biological, and cultural pest control procedures. Proper timing assists with economical and efficient results. Degree-day accumulations are used in control programs for many *Diptera* including the apple maggot, *Rhagoletis pomonella* (Walsh) (Laing and Heraty, 1984), the sugarbeet root maggot, *Tetanops myopaeformis* (Roder) (Whitfield, 1984), the carrot rust fly, *Psila rosae* (F.) (Getzin and Archer, 1983), the cabbage maggot, *D. radicum* (Wyman et al, 1977) and the onion fly, *D. antiqua* (Meigen) (Liu et al, 1982).

Degree-day models have been developed for *D. radicum* and *D. platura*, but have not been documented for *D. floralis*, *D. planipalpis* or *D. florilega*.

D. radicum

D. radicum has a mean air thermal unit requirement of 653° C degree-days (DD) for each generation, assuming a developmental threshold of 6.1° C (Eckenrode and Chapman, 1972).

Estimates of the number of air degree-days above 6.1°C for the emergence of *D. radicum* from overwintering pupae have ranged from 101-116 (Nair and McEwen, 1973), 166 (Wyman et al., 1977), 166-208 (Eckenrode and Chapman, 1972) and 193 (Matthewman and

Harcourt, 1971) in North America to 134-194 (Coaker and Wright, 1963) in the United Kingdom.

Differences may be due to the different methods used to record the times of fly emergence. Coaker and Wright (1963) used small cages erected over *Brassicae* host plants, whereas Eckenrode and Chapman (1972) used baited cone screen traps and Wyman et al (1977) used sticky traps which would capture only active flies.

Populations of flies may develop at different rates. Finch and Collier (1983) found genetically based differences in *D. radicum* that resulted in two variable peaks of fly emergence. They classified overwintering pupae into early-, intermediate-, and late-emerging types.

Other workers have also used a 4°C developmental zero for *D. radicum* developed in England. Collier and Finch (1985) estimated 179 ± 8 soil degree-days and 230 ± 10 air degree-days for 50% emergence, using a 4°C developmental zero. Steiner (1986), using 4°C with Collier and Finch's estimates, predicted May 20 for 50% emergence in Vegreville, Alberta. That year eggs were found on plants beginning May 25.

D. platura

The seed corn maggot, *D. platura*, was reported by Sanborn et al (1982) to have a developmental zero of 3.9°C with a total of 376°C air degree-days needed for development from egg to adult. Heat unit summations above 3.9°C averaged 30, 204, and 142 degree-days for the egg, larval, and pupal stages, respectively. These figures were arrived at by using controlled temperature chambers, and could be considered air or soil degree-day summations.

Funderburk et al (1984), using a 3.9°C developmental zero with soil temperatures, found a 50% capture of the overwintered generation adults at 190 degree-days but the first spring adult-to-adult peak required 492 degree-days. Higley and Pedigo (1984) found close agreement with the observed heat unit requirements of Sanborn et al (1982).

OBJECTIVE:

a) To determine *Delia* species diversity by pan trap collections in canola over one season.

b) To determine the number of generations of key *Delia* species in the Peace River Region by calculating degree-day accumulations, air and soil, and comparing them to known developmental requirements and degree-day summations.

MATERIALS AND METHODS:

Population diversity and trends of root maggot species were studied in a canola variety trial (see Figures 2, 3 and 4) established near Grande Prairie, Alberta in 1990. Plots were located in part of the SE 11-73-6-W6, consisting of the south eastern 28.33 ha (70 acres) of the quarter section.

The variety trial consisted of four cv of *B. rapa* ('Tobin', 'Colt', 'Horizon' and 'Parkland') and one cv of *B. napus* ('Westar'). These cultivars were treated at 562ml per 25kg of seed, with Vitavax® RS

Flowable (Uniroyal Chemical) consisting of a mixture of carbathiin, thiram, and lindane. An additional treatment included 'Tobin' sown without the Vitavax seed treatment to determine if the seed treatment affected root maggot survival, or if more root rot attracted adults for oviposition. All seeds used had been inspected for the virulent strain of Blackleg of canola (*Leptosphaeria maculans*).

Each of these 6 canola treatments were planted in 7m x 33m plots on June 3 using a CI-Noble 2200 hoe drill. Seeding depth was 2.5cm, at a rate of 8kg seed/ha, and each plot was sown with 50kg/ha of fertilizer mix 16-20-0-14. Two weeks before, the field had been treated with Rival (trifluralin) at .5 l/ha to control a number of grassy and broadleaved weeds during the growing season. The 6 canola treatment plots were arranged side-by-side to form blocks 42m long x 33m wide (see Figure 3). Treatments within blocks were randomized and the blocks were replicated 8 times side-by-side in a single row (336m long x 33m wide).

Yellow pan traps were used to monitor population trends of root maggot species during the study. The traps were obtained from Dr. G. Griffiths (Department of Entomology, University of Alberta, Edmonton), and were used by him in previous work to monitor *Delia* species (Griffiths, 1985, 1986a, 1986b, 1986c). A trap was a yellow-painted "Duraware 98" circular bowl (11cm deep x 20.5cm inner diameter) presenting an opening of approximately $330cm^2$. The reflectance spectrum of the yellow paint used was not available. The traps were established on June 5 in each of the 48 treatment plots, positioned 10m into each plot from the west edge, and 3m from each side. The pans were buried half-way into the ground, and were half filled with Galts solution, prepared from an equal mixture of glycerol and water saturated with picric acid, giving it a yellow color (Griffiths, 1986a). Galts solution was used so that comparison with the studies of Griffiths would be possible.

Trap collections were made weekly from June 11 to August 31. Insects from the pan traps were transferred to preserve jars, and later to vials filled with 70% ethanol. Traps were cleaned as required and Galts solution added when necessary. Flies collected were identified using keys provided by Brooks' (1951) and Griffiths' (1991b). A representative sample of flies was sent to Dr. Griffiths on March 21, 1991 for species verification.

During the season, notes were kept on dates of bloom, seed set, and developmental differences between canola varieties. In late August, an attempt was made to evaluate root rot and root maggot infestations in each canola variety. Because of a summer drought, however, the ground was extremely hard to work, therefore the soil surrounding the roots could not be sampled.

A mowed strip, 1m wide, was established and maintained around the periphery of the plots. A weather station was established in the field on July 12, 1990, located in a buffer zone of 'Tobin', immediately west of the plots. The station consisted of a Campbell Scientific Canada Corporation model CR-21 datalogger. Temperature sensors were manufactured by Campbell Scientific, using a Fenwal UUT51J1 thermistor as the active element built into a waterproof enclosure with linearization resistors. The air temperature sensor

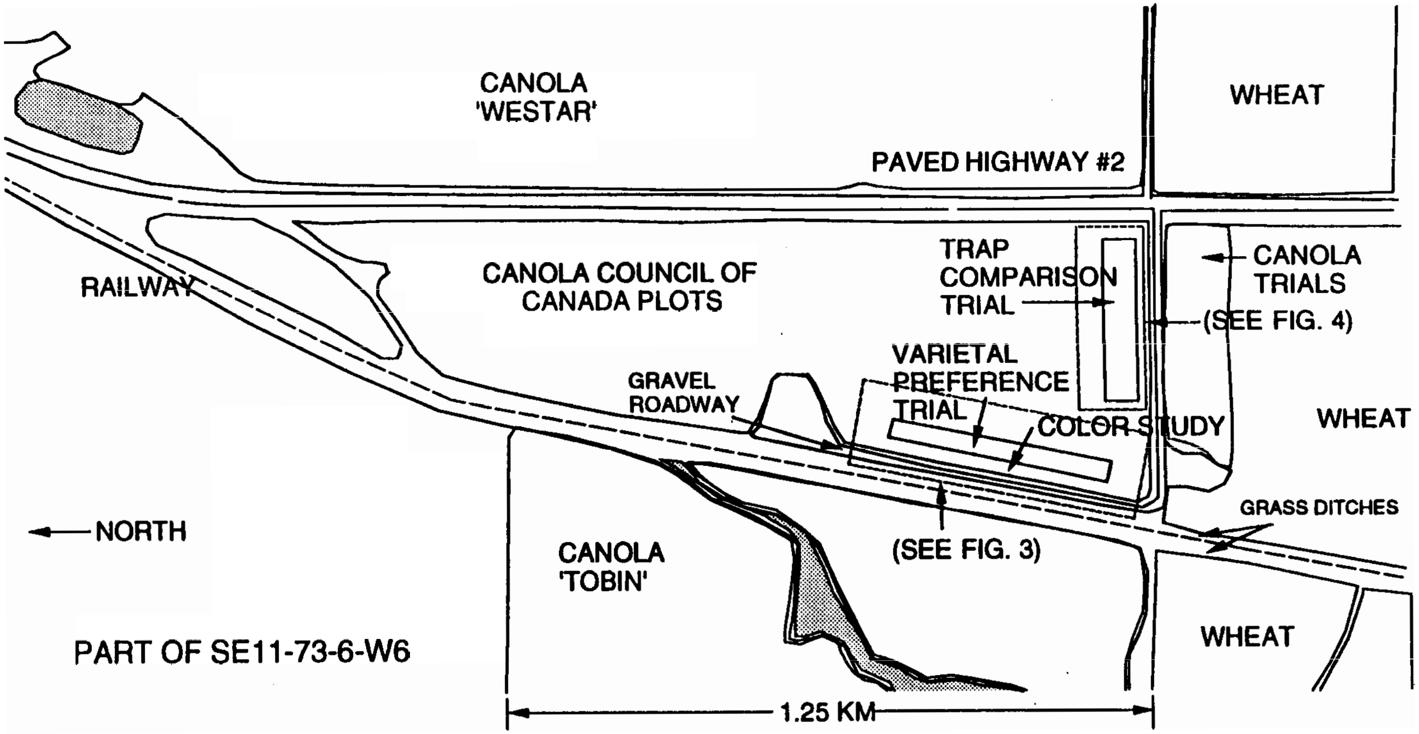


Figure 2. Plot plan showing field layout for: Varietal Preference, Color Study, Trap Comparison plots, and associated vegetation or crops.

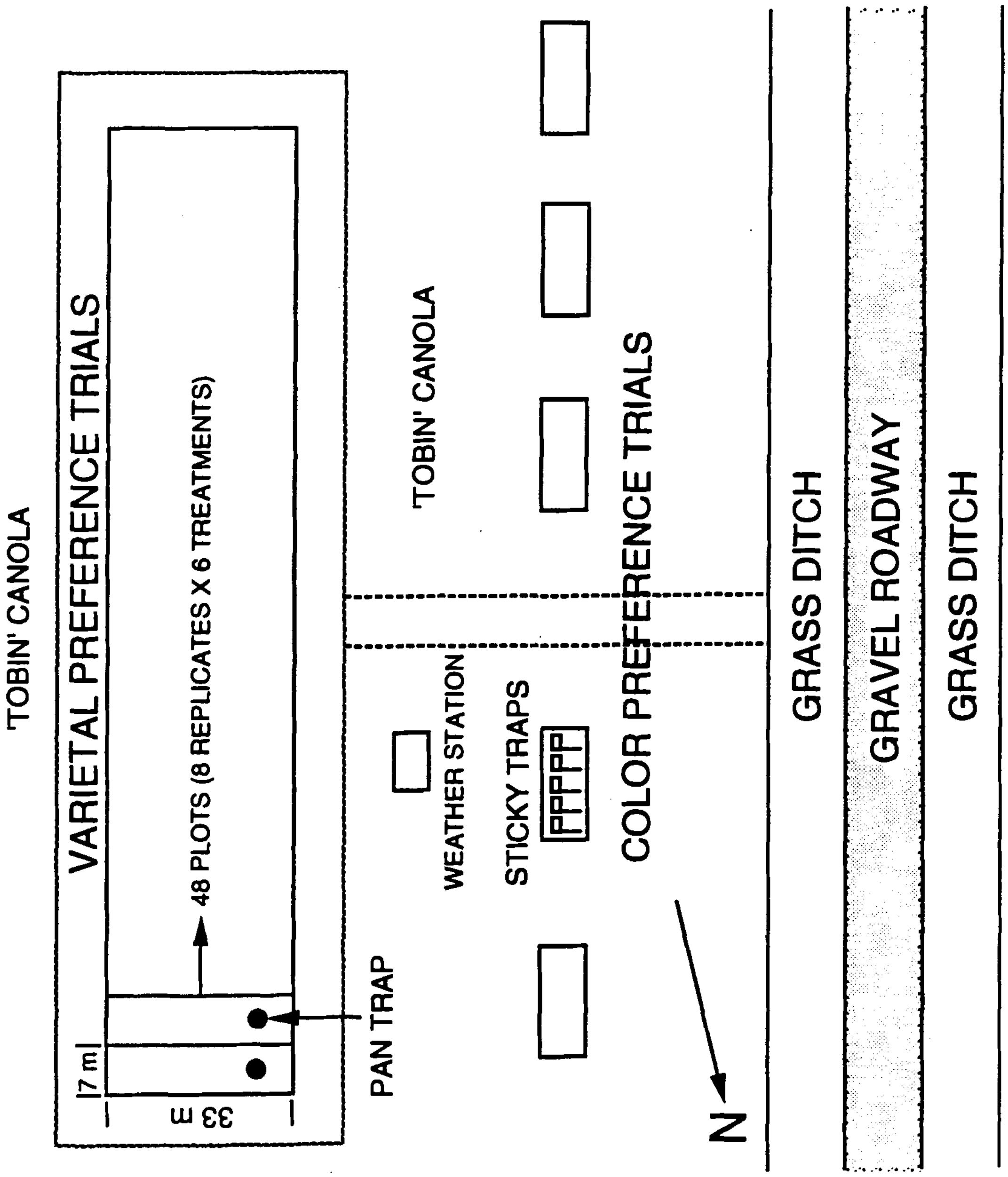


Figure 3. Plot layout of the Varietal Preference Trial and Color Preference Trial. (See Figure 2. Diagram not to scale.)

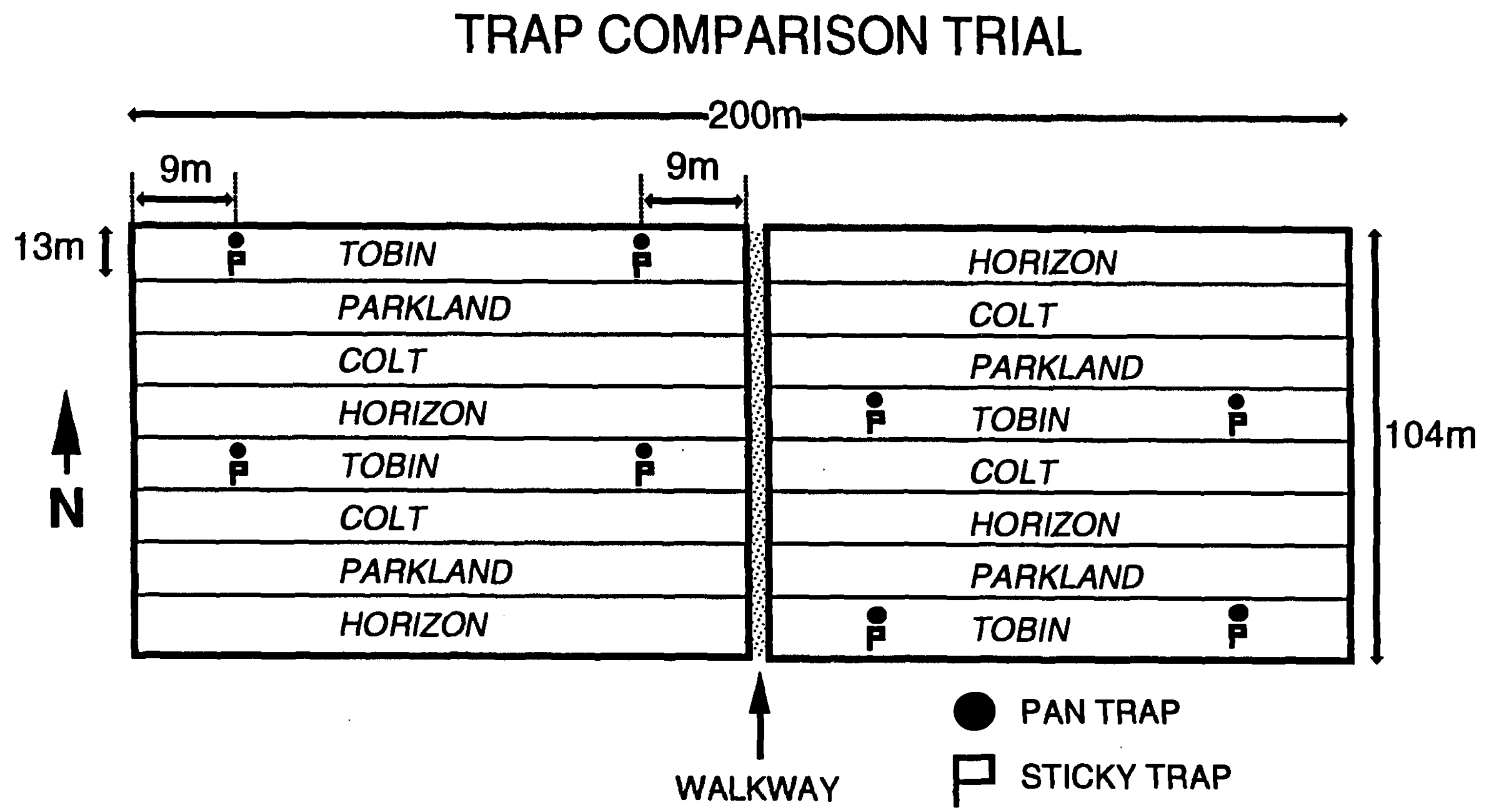


Figure 4. Plot layout of the Trap Comparison Trial.
(See Figure 2. Diagram not to scale.).

was properly shaded and placed at an elevation of approximately 1.4m above ground. The soil temperature sensors were inserted horizontally in the soil in order to minimize heat conduction from the surface. These sensors were placed at depths of 5cm and 10cm below the ground. The rain gauge was of the tipping bucket design, with a sensitivity of 0.254mm per tip (Dr. Peter Mills, Personal communication).

Weather information was also available for the entire 1990 field season from the Beaverlodge Agriculture Canada Research Station, located 40 km west of the plot site. Conveniently, both sites were located on Landry clay loam to loam soils having similar characteristics. Soil temperatures at Beaverlodge were recorded at 5, 10, and 20cm soil depth, at 8:00 A.M. and 4:30 P.M. daily. The station located at the plots was operated from July 12, 1990 to September 10 of that year.

RESULTS AND DISCUSSION:

DELIA SPECIES DIVERSITY AND ABUNDANCE:

Delia spp. identified were *D. radicum*, *D. floralis*, *D. planipalpis*, *D. platura* and *D. florilega*. A random sample of 64 identified flies were sent for independent verification. One *D. florilega* male had been miskeyed as *D. planipalpis*, but all other specimens were correctly identified. Liu and Butts (1982) found the same species except for *D. floralis*. Their collection was matured from pupae collected at one site, near Smokey Lake, 90km. northeast of Edmonton (Figure 1). Griffiths (1985, 1986a, 1986b 1986c) did not include *D. platura* or *D. florilega* in his discussion of *Delia* captures, although he took them in the pan traps during his studies (Dr. G. Griffiths, personal communication).

In relative abundance of adults captured from June 11 to August 31, 1990, *D. platura* (1038 females; 661 males) was the most abundant, followed by *D. radicum* (452 females; 302 males), *D. planipalpis* (145 females; 465 males) and *D. floralis* (255 females; 83 males).

D. radicum adults (male and female) (Figure 5) appeared in pan traps in the initial June 11 collection. The catch dropped off on June 15, and remained low until the August 3-31 collection period. The decline in numbers of all species trapped on June 15 may have been caused by heavy rains during that collection period. The pan traps were soiled by rain splash, making them less attractive. All traps were cleaned and refilled with new Galts solution on that date. The data indicate two population peaks, one occurring sometime in the spring, probably preceding the June 11 collection, and the other in August. Female captures were higher on all collection dates except on August 31, when males were slightly higher (98 vs 90).

These data compare favorably with the work of Steiner (1986), who observed separate egg laying peaks in *D. radicum* on rutabagas, on June 23 and September 2 near Edmonton. Although Steiner did not use traps to monitor *D. radicum* flight periods, the widely separated egg laying periods indicate two distinct adult flights. My work suggests that the two flight periods observed in the Peace River Region in 1990 occurred earlier than those in Steiner's study.

Griffiths (1986b), using 12 sticky traps and one pan trap at two locations near Smokey Lake, found that *D. radicum* adults appeared as early as May 11-14, peaked between June 1 and 20, and tapered off by the end of July. Trapping ended on August 9, at which time numbers were low. The adult peak observed in my study in August, however, suggests that Griffiths may have found another adult flight had his trapping continued later in August, 1985.

Griffiths (1986c) found low numbers of *D. radicum* about 90 km east of Grande Prairie in the Peace River Region in 1985. His sampling period, however, was limited to June 15-July 2. Populations of *D. radicum* in my 1990 study were also very low during that period, but were taken in higher numbers just before, and again one month later. Since I took greater numbers of *D. radicum* than *D. floralis* during the 1990 growing season, Griffiths' (1986c) conclusion that *D. floralis* is the dominant root maggot in the Peace River Region may be incorrect.

D. floralis adults captured in pan traps (Figure 6A) were similar in abundance to *D. radicum* (Figure 5) on the initial June 11 collection date, but occurred in higher numbers from late June to mid-July. As was observed for *D. radicum*, *D. floralis* adult captures began to increase in traps on August 3, with a pronounced peak capture occurring on August 17. Female captures were always more abundant, except in the July 6 and 13 collections, when males were 2-3 times the female numbers.

Griffiths' (1986c) work in the Edmonton area shows early trap catches similar to those obtained in my study. He reported that *D.*

floralis adults first appeared in the second week of June. Captures in canola remained low until mid-July, when they ceased, and data collection ended on August 9. Griffiths' (1986c) data for the Peace River Region were too limited to make comparisons with mine. Trap captures of *D. floralis* in my plots reflect Griffiths' Edmonton area collections except in the fall, when I took a second adult population.

D. planipalpis captures (Figure 6B) in June and July were similar to those of *D. radicum* (Figure 5). The numbers of adults captured during the peak of activity in August were also similar to those of *D. radicum*, but the time of peak capture and subsequent decline in numbers trapped resembled those of *D. floralis.* In early June, females were captured in higher numbers, whereas in the August peak male abundance was much higher.

Kelleher's (1958) work on root maggots attacking radish in Manitoba showed that first-generation adults of *D. planipalpis* emerged at the end of June or the first week in July. A peak of second-generation fly emergence occurred during the first week of August of 1953. My trap captures of *D. planipalpis* in canola are similar to those in Kelleher's (1958) report.

D. platura captures (Figure 7) varied more in numbers over time than the other three species, with peak captures occurring on June 11 and 22, July 13, and less defined increases on August 3 and 24. The major peaks of activity observed in August for adults of *D. radicum*, *D. floralis* and *D. planipalpis* were not observed for *D. platura*. Female abundance was higher than male by X2 in June trap captures, but variable during the rest of the collection period.

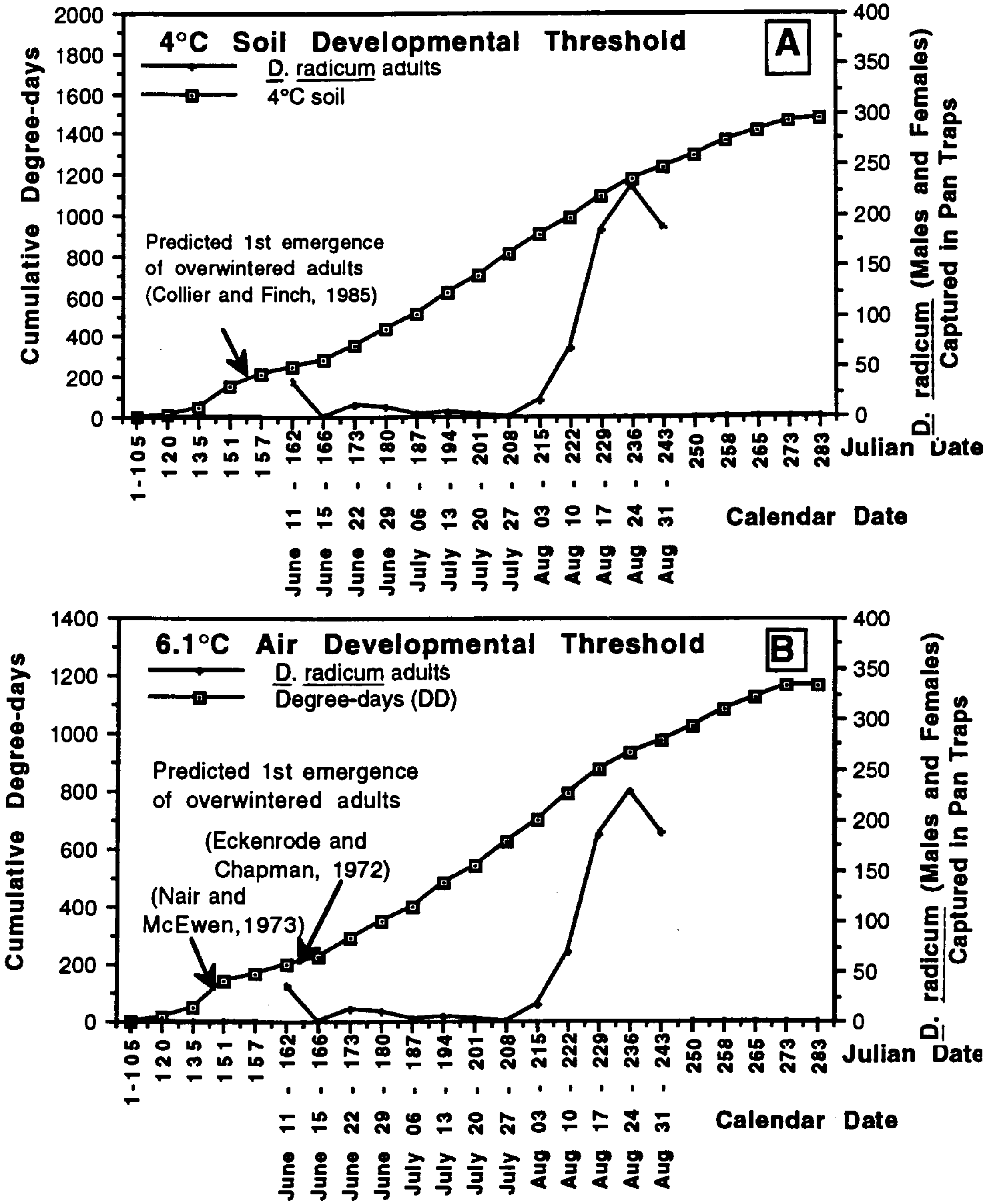


Figure 5. Degree-day accumulations using 4°C soil (A) and 6.1°C air temperatures (B) as developmental threshold requirements for *D. radicum* compared with captures of adult *D. radicum* males and females in pan traps in canola plots for 13 trapping periods in 1990.

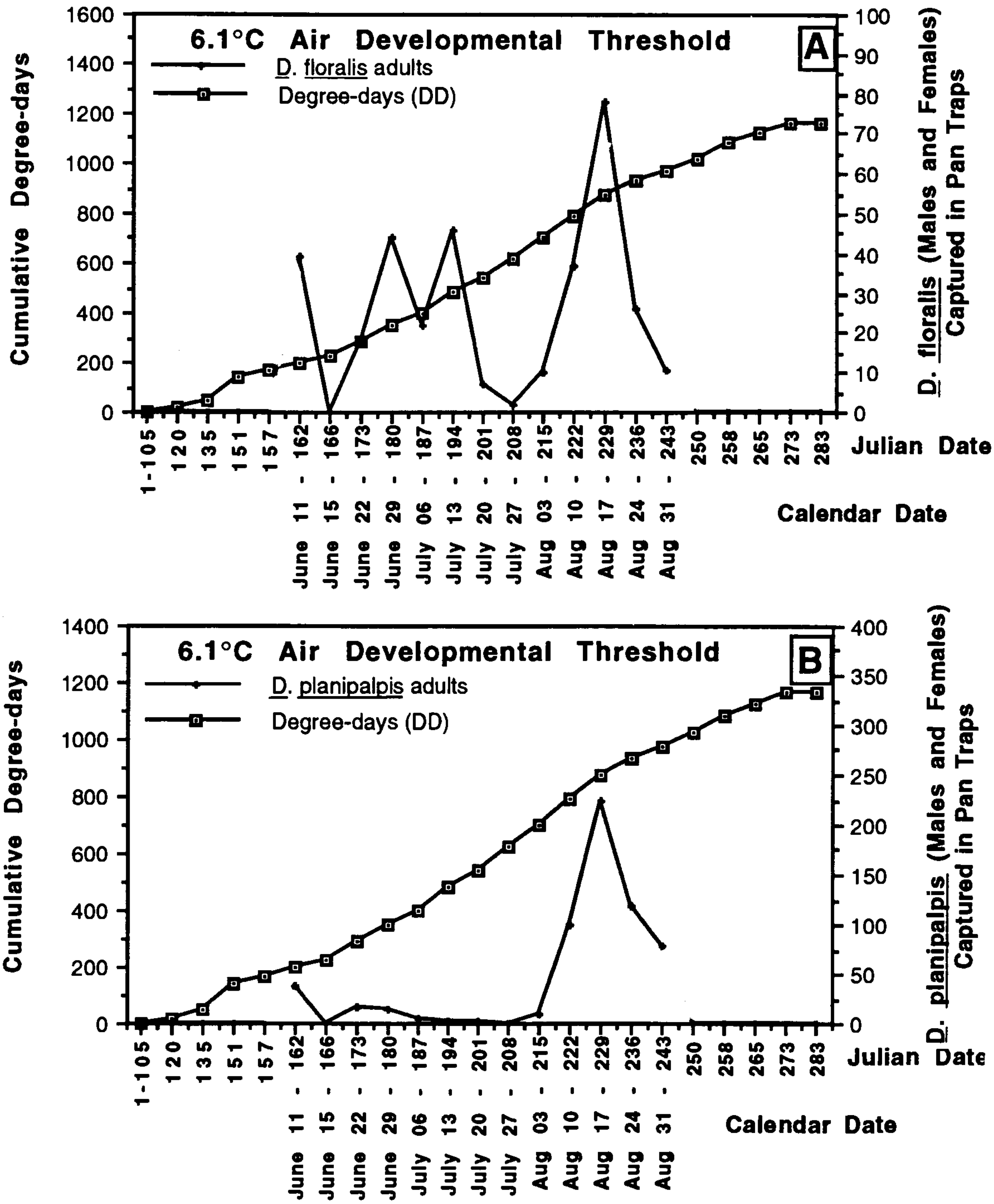


Figure 6. Degree-day accumulations using a 6.1°C air temperature as the developmental threshold requirement for *D. floralis* (A) and *D. planipalpis* (B) compared with captures of adult males and females of both *Delia* species in pan traps in canola plots for 13 trapping periods in 1990.

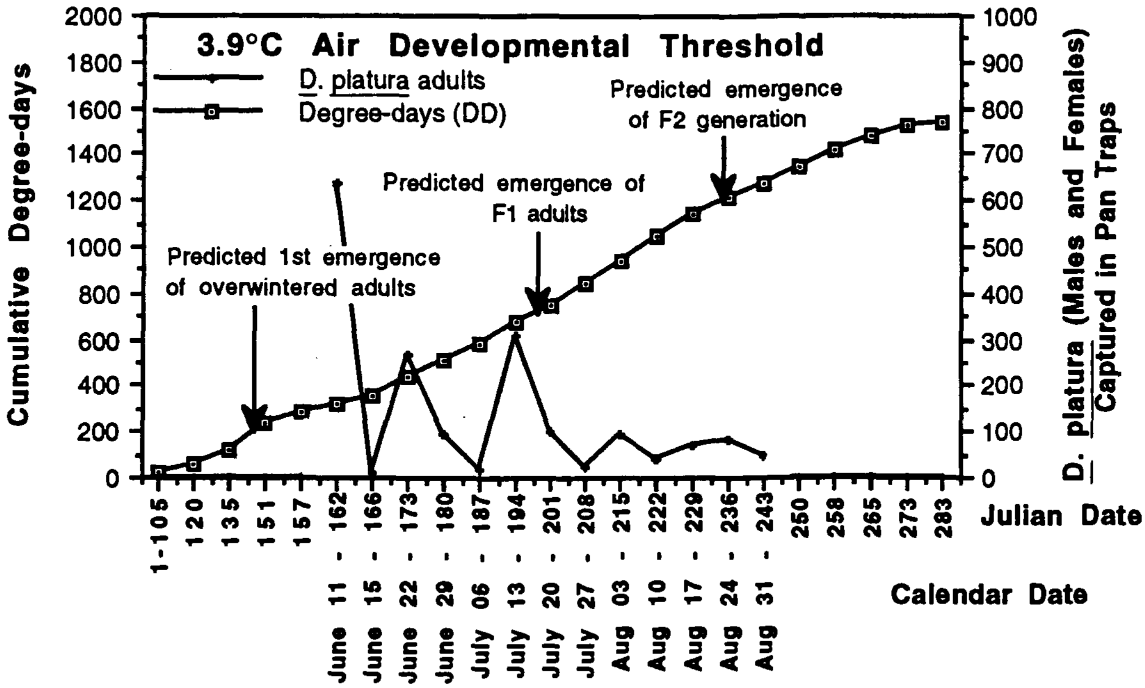


Figure 7. Degree-day accumulations using a 3.9°C air temperature as the developmental threshold requirement for *D. platura* compared with captures of adult males and females of *D. platura* in pan traps in canola plots for 13 trapping periods in 1990. Arrows indicate predicted emergence of 3 adult generations using the degree-day information of Sanborn et al, 1982.

Trap captures of *D. platura* were in close agreement with other research findings (Sanborn et al, 1982; Higley and Pedigo, 1984; and Funderburk et al, 1984). Funderburk et al (1984) found two spring generations in central Iowa, but the populations were uncommon or absent in the summer and fall, strongly suggesting aestivation.

Captures from my plots revealed several population peaks. After the July 13 peak populations dropped off to comparatively low numbers, but remained present up to the final trap collection on August 31. Aestivation may not have been complete but over part of the population. Two peaks, on June 11 and 22 were probably one extended peak. The trap capture on June 15 was low because of wet, windy weather and discoloration of the yellow pan traps, since soil splashed into the pan during rains and made them unattractive.

D. florilega and *D. platura* are morphologically similar, and only the males can be distinguished easily under a dissecting microscope. *D. florilega* males were captured in low numbers in the pan traps during the growing season, and therefore were not included in the population graphs. Difficulty in keying female *D. florilega* and *D. platura* may have resulted in some of the females being grouped together.

POPULATION TRENDS AND DEGREE-DAYS:

Weather data were gathered from the canola plots only between July 12 to September 10, and therefore did not cover the entire 1990 growing season. A comparison of the air and soil temperatures recorded at the canola plots with those from the

Beaverlodge Research Station, showed that the two areas had similar degree-day accumulations. Data obtained from Beaverlodge, therefore, were used to approximate the degree-day totals for *Delia* spp. development at the test site.

D. radicum

Using 4°C as the developmental zero for *D. radicum*, 50% emergence of adults from pupae overwintered in 1989-1990 should have occurred at 179 ± 8 soil and 230 ± 10 air cumulative degree-days, or around June 2 (Collier and Finch, 1985)(Figure 5A). Initial emergence of *D. radicum*, therefore, would have begun before the first pan trap collections on June 11. Evidence for this is that 253 soil and 276 air degree-days had accumulated by June 11, and trap catches declined after that date.

Using 6.1°C as the developmental zero to estimate initial emergence, adults could have emerged as early as May 27 using the 101-116 degree-day estimate of Nair and McEwen (1973), or not until June 11 using the higher 166-208 degree-day estimate of Eckenrode and Chapman (1972)(Figure 5B).

Catches of *D. radicum* were low until the August 3 trap collection date, at which time adult populations began to increase (Figure 5). This was probably the beginning of the first (or summer) generation flight. Using the 6.1°C developmental zero, a total of 695 soil and 702 air degree-days had accumulated by August 3. The peak trap captures occurred on August 24, when a total of 926 soil and 993 air degree-days had accumulated. If oviposition by the *D.*

radicum summer generation began one week after females were first captured on August 3, a total of 366 soil and 376 air degree-days remained available to the end of the year.

Assuming a 6.1°C developmental zero, Eckenrode and Chapman (1972) estimate that 653 degree-days are required for each *D. radicum* generation. This figure could not be confirmed for development between the overwintering and the first adult generation, because the traps were set out after the spring emergence, and 50% emergence of the spring flight could not be determined from these data. Since only 366 soil and 376 air degree-days remained available from August 10 onward, and 653 degree-days are required for each complete generation (Eckenrode and Chapman, 1972) the development of a complete second, or summer adult *D. radicum* population would not have been possible in 1990. Whether the remaining cumulative degree-days are ever sufficient at this latitude to take the second generation to an overwintering pupal stage, was not determined from this study.

D. floralis and *D. planipalpis*

Although degree-day models and developmental zeros have not been determined for *D. floralis* or *D. planipalpis*, the simultaneous emergence of their summer generations on August 3 (Figure 6) suggests, but does not confirm, a similar developmental rate to that of *D. radicum*.

D. platura

Using a 3.9°C developmental requirement for *D. platura,* a total of 1495 soil, and 1538 air degree-days were compiled over the 1990 season. According to Funderburk et al (1984), 50% emergence of overwintered *D. platura* in Iowa occurred around 190 degree-days, with 492 degree-days between adult to adult peaks. Air temperatures gave the best predictions in their studies. In my study, 190 air degree-days were accumulated on May 26. Using the 492 degree-day requirement of Funderburk et al (1984), subsequent adult peaks of *D. platura* should have occurred around July 13 and August 17 (Figure 7).

Collections were first taken from field traps on June 11 (325 air degree-days) and high levels of *D. platura* were captured at that time. It is likely that the peak *D. platura* capture on June 22 was partly from the overwintered generation, and was not a separate spring generation. Another peak of *D. platura* adults was observed on July 13, at which time 678 air degree-days had accumulated. This peak coincided almost exactly with the predicted second adult flight using the air degree-day calculations of Funderburk et al (1984). Populations of *D. platura* were low in August, and no definite peaks were observed to verify the predicted August 17 emergence of the final adult flight.

Higley and Pedigo (1984) found *D. platura* to have aestivating generations in Iowa. When air temperatures exceeded 29°C, many *D. platura* adults died. Given the worldwide distribution of the seed corn maggot, this species must have a mechanism for escaping high temperatures.

Mean air temperatures at the plots were in the 20°C range from July 25 to August 12. Maximum temperatures reached or exceeded 29°C on 5 days during that time. In temperate regions, females may rest in sheltered habitats, such as woods, to escape high temperatures, but some researchers have found no evidence of aestivation (Strong and Apple, 1958).

The expected *D. platura* population in August did not occur in high numbers, as might have been expected from the high population occurring earlier. The low numbers might have been due to the adults no longer being attracted to pan traps, no longer attracted to the crop or, entering an aestivation between July 25 and August 12.

CONCLUDING DISCUSSION:

My study on *Delia* spp. over an entire growing season revealed much more about the populations that infest canola in the Peace River Region than was previously reported. Griffiths (1986c) report that *D. radicum* was largely absent from the Peace River Region and that the dominant root maggot was *D. floralis* is now questioned. The relative abundance of adult *D. floralis* captured in pan traps, in comparison with *D. radicum,* over the entire growing season in my study were 31% and 69% respectively, whereas relative abundance of adults from June 11 until mid-July, the reported egg laying period, was 68% and 32% respectively. From this information the species would appear codominant in the Peace River Region.

Brooks (1951) seems to have thought that there could be a partial second generation of *D. floralis* in Canada in some years (the species being stated to have "1 to 1.5 generations" in his Table 1). Griffiths (1986c) reported *D. floralis* to be exclusively univoltine throughout its North American range. His statement may be too generalized. My work supports the Brooks report. Whether the eggs laid by the second generation of adults reach the overwintering pupal stage was not determined in my study, but if the overwintering pupal stage is obtained, then management practices present themselves (e.g. fall cultivation, late seeded trap crops, etc.).

The degree-day data obtained in this study did not cover the entire emergence or life cycle of the *Delia* spp. found in the Peace River Region. Trap captures compared with known degree-day information indicate the possibility of a fall generation in *D. radicum*, *D. floralis* and *D. planipalpis*. Kelleher (1958) found a second-generation of *D. planipalpis* emerging in the first week of August in Manitoba. He reported that overwintering puparia were formed after the third week in August. It would appear from his report that only a limited number of degree-days are needed to develop the overwintering puparial stage in *D. planipalpis*. Further research is necessary before these statements can be confirmed or disputed.

The relative impact on canola of the four *Delia* spp. reported in my study is unknown. The high number of *D. platura* captured early in the growing season indicates that a high damage potential exists if that species inflicts damage following primary invasion by larvae of *D. radicum*, *D. floralis* and *D. planipalpis* or alone as has been demonstrated in other crops by other researchers. Further work is needed to ascertain the combined or individual impact of *Delia* spp. on canola in this region, especially during the critical spring generation when most damage to canola occurs.

CHAPTER 3

VARIETAL PREFERENCES BY ROOT MAGGOTS:

INTRODUCTION:

In Europe and Asia, where the cultivation of cruciferous crops is an ancient and well established practice, most of the insect pests of oilseed *Brassicae* crops are crucifer specialists.

Many of the pests infesting crucifer crops in North America, such as the crucifer flea beetle (*Phyllotreta cruciferae*, Goeze), root maggots (*Delia* spp.) and the diamondback moth (*Plutella xylostella* (L.)), are also crucifer specialists. Most of these pests were introduced from Europe or Asia and became pests of cruciferous crops before oilseed *Brassicae* crops were introduced (Lamb, 1989).

VARIETAL PREFERENCE, NONPREFERENCE AND RESISTANCE:

For many insects, varietal preferences, nonpreferences or resistance mechanisms exist within species and cultivars in the *Cruciferae*. Preferences for certain hosts may be for oviposition, for feeding or both (Harborne, 1988).

In the *Cruciferae*, glucosinolates are assumed to have evolved as repellent substances. These volatile oils occur in the plants in bound form as thioglucosides (called glucosinolates) and are released enzymatically (hydrolyzed) by the enzyme myrosinase, yielding volatile isothiocyanates (Harborne, 1988).

The expanded use of canola and consequent increase in production occurred when plant breeders altered the chemistry of the seed. First, the fatty acid composition of the oil was modified to reduce the level of erucic acid, and then the levels of glucosinolates in the meal were reduced (Lamb, 1989). Often, insect preferences are influenced by glucosinolate levels found in the host plants. Glucosinolates in the *Cruciferae* serve as inhibitors for non-adapted species and stimulants for adapted species (Harborne, 1988).

Varietal preferences

Crucifer specialists and their parasitoids from at least four orders of insects are known to be attracted by volatiles produced by crucifers (Feeny et al., 1970; Read, 1970; Wallbank and Wheatley, 1979; Pivnick et al, 1990).

Pivnick et al (1990) found evidence that egg load in the diamondback moth (*Plutella xylostella* (L.)) was related to responsiveness to plant volatiles. Glucosinolate levels and their areas of concentration may change over time or growth stages. Cole (1980) identified volatiles produced by one *B. rapa* cv. 'Early giant' from seedling to eight weeks of age. Gluconasturtiin and epithiopentane were isolated from four-to eight-week-old plants. Peak release of gluconasturtiin was in four-to five-week-old plants.

Studies on the glucosinolate profiles in the seed, root, and leaf tissue of cabbage, mustard, rapeseed, radish and swede revealed major differences between the profiles in the same plant for all five species investigated (Sang et al, 1984). Even within the first 10-14 days after seeding in the *B. napus* cultivar 'Midas', the individual glucosinolates in different parts of the seedling appeared to vary independently and to be related to development of specific organs or tissues (McGregor, 1988). Dosdall (personal communication) found *B. rapa* plants to be more susceptible to infestation by root maggots (*D. radicum and D. floralis*) than *B. napus* plants, judging by the mean eggs laid per plant. Within *B. rapa* cultivars studied, 'Horizon' was the most susceptible to root maggot oviposition and 'Parkland' was the least. No explanation was given for the observed preference among species and cultivars.

Nonpreference

Antixenosis is a term suggested by Kogan and Ortman (1978) to describe plant properties responsible for nonpreference. This term translates as "something that keeps the guest away". It is meant to convey the idea that the plant is a bad host; therefore, it is avoided. An antixenosis has been identified as a mechanism of resistance in seedlings of mustard to flea beetle attack (Bodnaryk and Lamb, 1991a).

Mustard oils, chemically combined in glucosinolates, are commonly regarded as the factors responsible for the exclusive adaptation of a complex of insect pests, including the crucifer flea beetle (*P. cruciferae*), to *Brassicae* and related crucifers (Putnam, 1977).

Resistance

The reduction in pest numbers achieved through host plant resistance is constant, cumulative and practically without cost to the farmer (Maxwell, 1990). Within the *Cruciferae*, examples in North America include resistance in mustard seedlings to the flea beetle *Phyllotreta cruciferae* (Goeze) (Bodnaryk and Lamb, 1991a), resistance to three lepidopteran species and cabbage aphids by *B. oleracea* through glossy leaf wax (Stoner, 1990) and the influence of seed size in canola, *B. napus* L. and mustard, *Sinapis alba* L. on seedling resistance against flea beetles, *P. cruciferae* (Goeze) (Bodnaryk and Lamb, 1991b).

Individual species or cultivars also have varying abilities to recover from or adapt to attack by pests. Dosdall (personal communication) found that damage assessments of roots at the end of the season were significantly different between species, with *B. rapa* roots affected more severely than *B. napus* roots. McDonald (1985) considered the nature of root injury on 'Tobin' to indicate that the root system of *B. rapa* was resistant to attack from the cabbage maggot. Feeding injury at low larval densities resulted in only sub-surface penetration of the periderm and secondary phloem tissues with little effect on the storage or transport capacity of the root.

DELIA SPECIES HOST PREFERENCES:

Host preferences by *D. radicum* have been studied by several researchers (Hawkes and Coaker, 1979; Wallbank and Wheatly, 1979; Finch and Ackley, 1977; and Hawkes, 1974). Coaker (1969) found that oviposition by *D. radicum* was partly dependent on its receiving a contact stimulus from mustard oil glucosides, and the number of eggs laid was dependent on the glucoside concentration. In laboratory studies, Coaker (1969) found a 50% increase in the numbers of eggs laid around those rapeseed plants with the highest, as compared with the lowest, thioglucoside content.

Dispersal rates have been recorded to be at least three times faster when females were downwind of a *Brassicae* crop (Hawkes, 1974). Gravid *D. radicum* responded to *Brassicae* by flying upwind, so that it appeared that the attraction to host-plants was by way of anemotaxis stimulated by host-plant odor. Hawkes and Coaker (1979) found behavioral attraction of *D. radicum* to the host plant's odor, using cabbage plants to test visual and olfactory stimulation. Only gravid females showed oriented upwind responses to host plant odor; but visual stimuli had no effect. Using plant extracts to attract *D. radicum*, an extract of the swede cultivar 'Wilhelmsburger' was ineffective, a result correlated with its partial resistance to this pest in the field (Finch and Skinner, 1982).

Wallbank and Wheatly (1979) caught 11 times more female and 7 times more male *D. radicum* by using allyl isothiocyanate as bait in yellow water-pan traps, compared with nonbaited traps in a cabbage crop. Interestingly, allyl glucosinolate, which yields allyl isothiocyanate was not found in *B. napus* or *B. rapa* (Lamb, 1989). Based on examination of root damage under field conditions, McDonald (1985) postulated that plants of *B. rapa* cv 'Tobin', during the period from stem elongation through flowering (from four to six weeks post-seeding), may have been more susceptible to maggot attack by *D. radicum* than *B. napus* cv. 'Westar' seeded at the same time. An earlier or more attractive release of host volatiles would have stimulated more *D. radicum* females to oviposit.

No information on varietal preferences by *D. floralis* or *D. planipalpis* was found in the literature.

D. platura has been shown to exhibit egg laying preferences. Its ovipositional stimulants included seed or soilborne bacteria. Harmon et al (1978) found that treatment of squash seeds with thiram or captan increased oviposition of *D. platura* and attributed this to the low activity of these broad-spectrum fungicides on bacteria, permitting greater bacterial growth. Hough-Goldstein and Bassler (1988) found that three bacterial isolates, alone or in combination, stimulated oviposition.

OBJECTIVES:

The main objective here was to examine the relative abundance of adult populations of *D. radicum*, *D. floralis, D. planipalpis* and *D. platura* occurring in 5 varieties of canola during a complete growing season in the Peace River Region. This was to determine if preferences exist in some *Delia* spp. for certain canola varieties, which could then be used in the development of future pest management strategies.

An additional objective was to determine the relative damage inflicted on the roots of these canola varieties by maggots during the growing season. This objective was not met, however, because heavy spring rainfall was followed by a summer drought, which resulted in severe soil compaction, precluding root samples being taken as planned.

MATERIALS AND METHODS:

The experimental set-up was as described in Chapter 2, and was located in the varietal preference plot area (Figures 2 and 3). Statistical data obtained were analyzed by analysis of variance (ANOVA) after square root transformation, followed by Duncan's Multiple Range test (DMR) at the .05 significance level. DMR is independent of the analysis of variance table and F values could indicate a lack of significance between varieties. The square root (x + 0.5) transformation was applied to the number of flies captured to stabilize the variance.

Early in the growing season (June 15 to early August) captures of *D. radicum*, *D. floralis* and *D. planipalpis* during individual trapping sessions were low (Chapter 2, Figures 5 and 6). Overall trap catches for these species between June 11 and August 3 were therefore pooled for analysis. This was also done for *D. floralis* between August 3 and August 31. *D. platura* captures were more balanced and numbers were generally higher during the trapping periods. When *D. platura* captures were quite low they were eliminated from analysis.

RESULTS:

Analyses of numbers of male and female *D. radicum* (Figure 8) and *D. floralis* (Figure 9) trapped within different canola cultivars during one or more trapping interval revealed no statistically significant varietal preferences (See Appendix 1, Tables 1 and 2 for mean captures ± S.E. for, respectively, *D. radicum* and *D. floralis*).

Significantly ($P < .05$) higher catches of both male and female *D. planipalpis* in certain varieties were observed at intervals during the growing season (Figure 10). (See Appendix 1, Table 3 for mean captures ± S.E. for *D. planipalpis*). For males (Figure 10A), significant differences in captures between varieties were observed on August 17th ($P = .0006$), August 24th ($P = .015$) and on August 31st ($P = .0445$). No significant differences in male captures were ever observed between the 4 Vitavax-treated *B. rapa* varieties 'Tobin', 'Colt', 'Horizon' and 'Parkland'. Significantly higher numbers of males were captured in the untreated 'Tobin' plots than in the *B. napus* variety 'Westar' on the 3 dates mentioned. One or more of the four *B. rapa* varieties had significantly more males captured than did 'Westar' on August 17 or 31. Captures of males in the untreated 'Tobin' plots were significantly higher than in the treated 'Tobin' plots on August 17.

For female *D. planipalpis* (Figure 10B), significant differences in captures between varieties were observed only on August 17 ($P = .0062$). On that date, captures in the untreated 'Tobin' plots were significantly higher than in the treated 'Tobin', 'Colt', 'Parkland' and 'Westar' plots.

Significantly ($P < .05$) higher catches of both male and female *D. platura* were observed in certain varieties at times during the middle part of the 1990 growing season (Figure 11). (See Appendix 1, Table 4 for mean captures ± S.E. for *D. platura*). For male *D. platura* (Figure

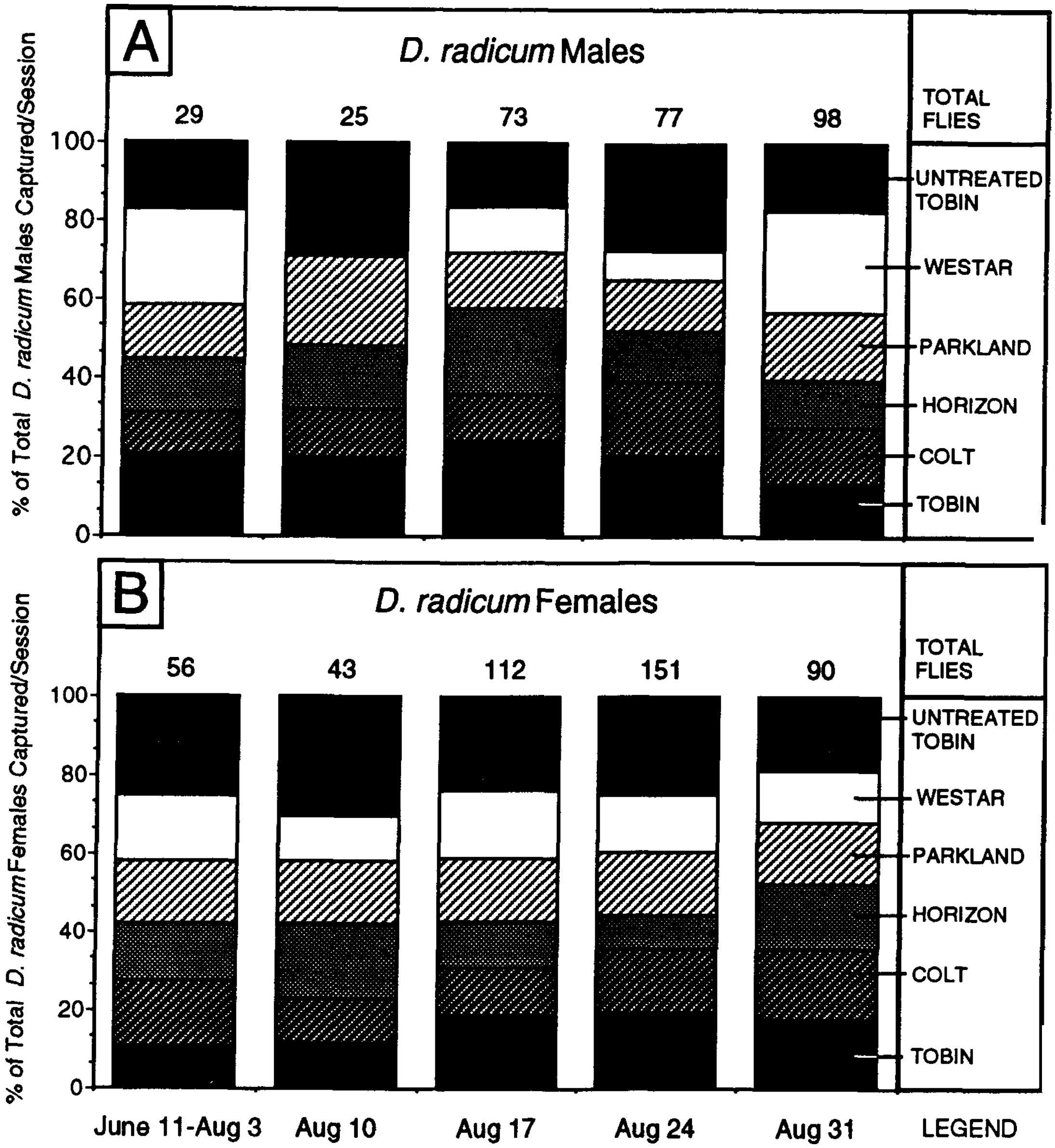


Figure 8. *D. radicum* males (A) and females (B) taken in pan traps (expressed as a percentage of total mean captures) during trapping intervals between June 11th and August 31/1990. June 11th to August 3rd data are pooled because of low numbers taken.

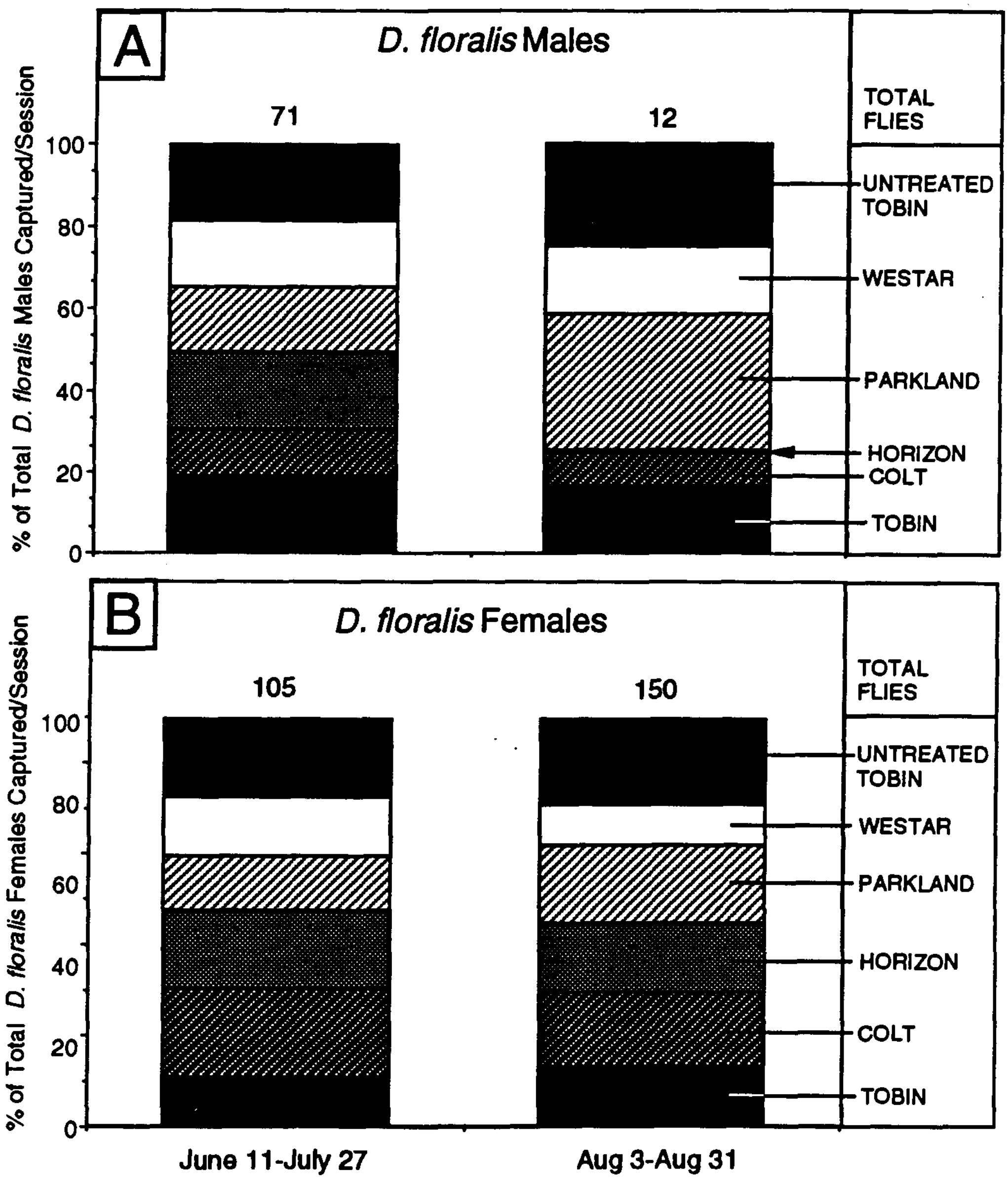


Figure 9. *D. floralis* males (A) and females (B) taken in pan traps (expressed as a percentage of total mean captures) during trapping intervals between June 11th and August 31/1990.

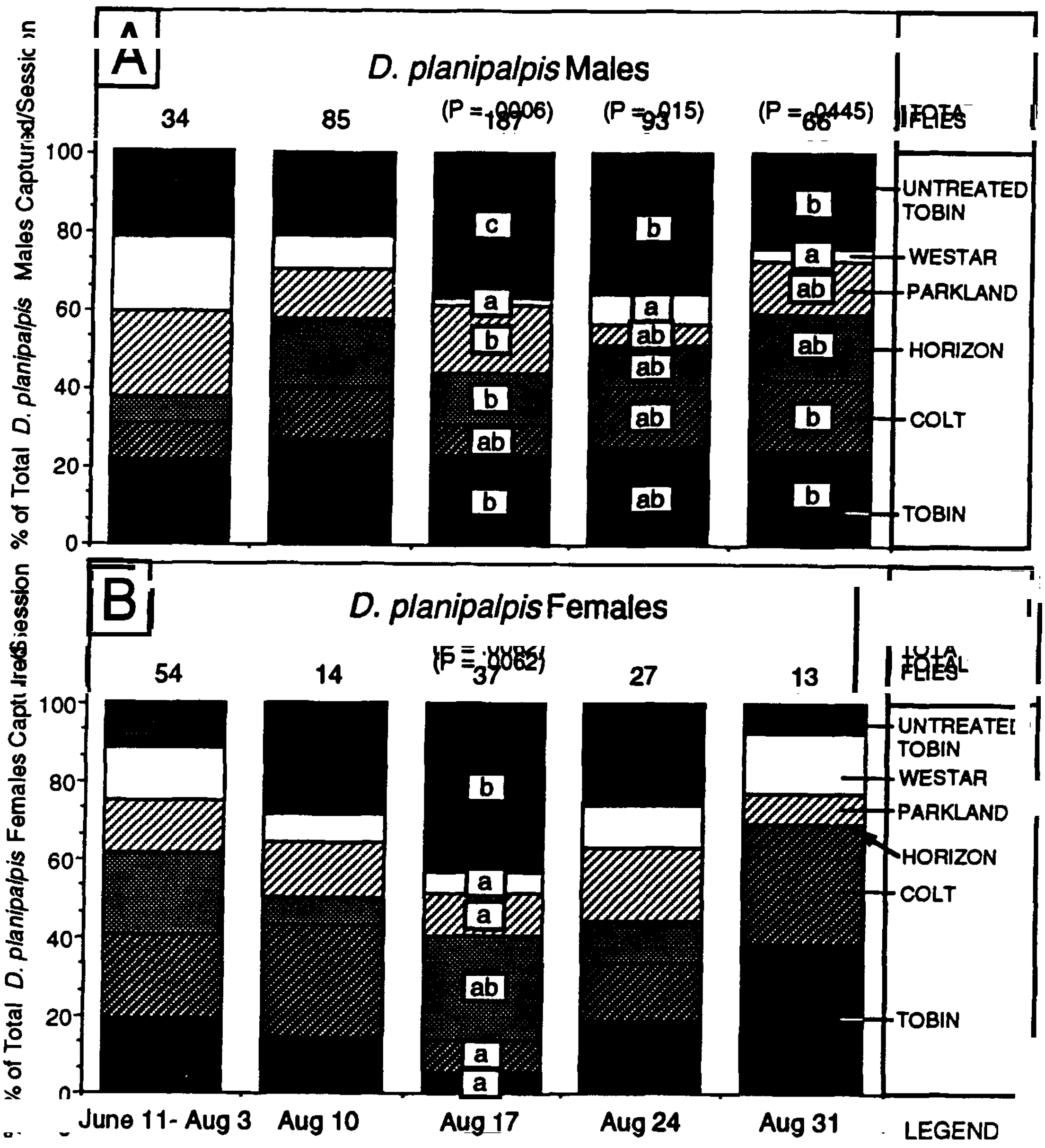


Figure 10. *D. planipalpis* males (A) and females (B) taken in pan traps (expressed as a percentage of total mean captures) during trapping intervals between June 11th and August 31/1990. Data from June 11th to August 3rd were pooled because of the low numbers taken.

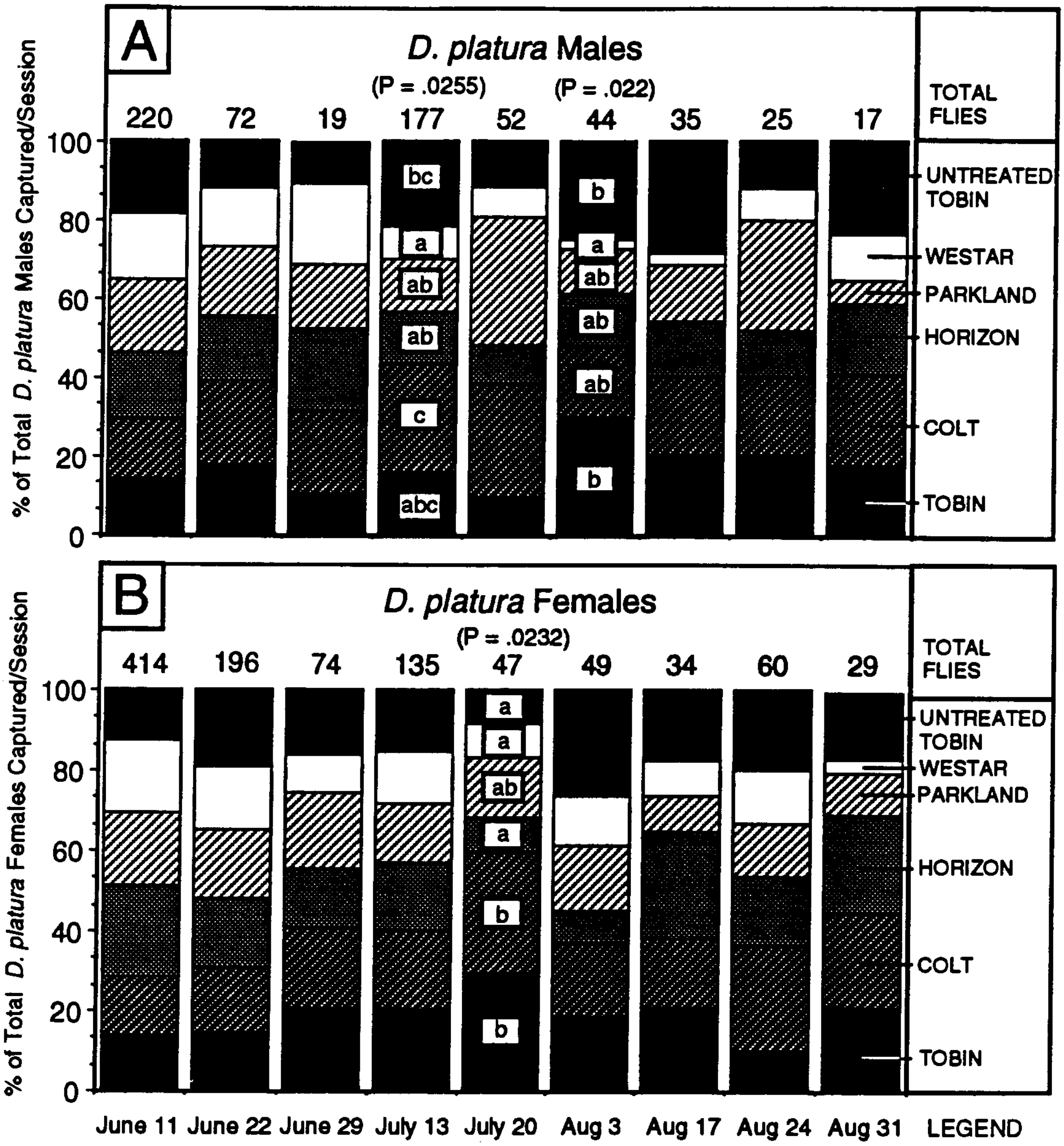


Figure 11. *D. platura* males (A) and females (B) taken in pan traps (expressed as a percentage of total mean captures) during trapping intervals between June 11th and August 31/1990. Trap collection dates with very low numbers are not included.

11A), significant differences in captures between varieties were observed on July 13 (P= .0255) and August 3 (P= .022). Among the four Vitavax-treated *B. rapa* varieties, significantly more males were caught in 'Colt' on July 13 than in 'Horizon' or 'Parkland', but not in 'Tobin'. No other differences in these four varieties were observed. Significantly higher numbers of males were taken in the untreated 'Tobin' plots than in the *B. napus* variety 'Westar' on the 2 dates mentioned. 'Colt', on July 13 and treated 'Tobin' on August 3 had significantly more males than 'Westar'. Captures of males in the untreated 'Tobin' plots were never significantly higher than in the treated 'Tobin' plots.

For female *D. platura* (Figure 11B), significant differences in captures between varieties were observed only on July 20 (P= .0232). On that date, captures in 'Colt' and 'Tobin' were significantly higher than those in the untreated 'Tobin', 'Westar', and 'Horizon' plots.

DISCUSSION:

Major differences in the glucosinolate contents between the seed, leaf and root of rape have been recorded (Sang et al, 1984), while McGregor (1988) found the individual glucosinolates in different parts of the seedling to vary independently and to be related to the development of specific organs or tissues. Glucosinolates have been shown to affect host selection behaviors in a number of crucifer specialist insects, such as the diamondback moth (*P. xylostella*) (Nayar and Thorsteinson, 1963; and Pivnick et al,

1990) and the crucifer flea beetle (*Phyllotreta cruciferae*) (Putnam, 1977). Since glucosinolates differ in composition and quantity from variety to variety and within varieties throughout the growing season, it is reasonable to expect that *Delia* species may prefer certain varieties over others, and that any preferences may be influenced by the age of the plants.

Dosdall (personal communication) found significant egg laying preferences for *D. radicum* and *D. floralis* within canola cultivars. *B. rapa* plants were more susceptible to infestation by these root maggots than *B. napus* plants in terms of mean eggs laid per plant and mean root damage rating per plant. Preferences for oviposition between cultivars within *B. rapa* and *B. napus* were also observed. For example, Dosdall found that within the *B. rapa* varieties, 'Horizon' was more susceptible than 'Parkland' to root maggot damage. McDonald (1985), suggested that the variety 'Tobin' was more susceptible to attack by *D. radicum* than 'Westar' during the period of stem elongation through flowering (4-6 weeks post seeding).

My results did not reveal significantly higher numbers of *D. radicum* or *D. floralis* in any of the varieties tested during the 1990 growing season. Although these results appear to conflict with the findings of McDonald (1985), it should be noted that populations of *D. radicum* and *D. floralis* were quite low between July 3 and July 17, 1990, which was McDonald's suggested susceptible period of 4-6 weeks post seeding (Chapter 2, Figure 5 and 6A). Although differences in adult captures between varieties were not observed in my study, this does not rule out the possibility that within-variety preferences for *Delia* oviposition (and thus root damage) were still occurring. Unfortunately, this could not be determined in 1990, since root samples could not be taken as planned, due to the highly compacted soil in the test area.

Numbers of *D. planipalpis* males were significantly higher in treated 'Tobin' (and in some of the other *B. rapa* varieties) than in treated 'Westar' (Figure 10A), but not until the August flight period. This could indicate: a) that natural volatiles produced by undamaged, treated 'Tobin' were more attractive to male *D. planipalpis* at that time; b) that adult emergence from damaged roots in the 'Tobin' plots was greater than from the 'Westar' plots; c) that a higher level of root damage was occurring in the 'Tobin' plots, the volatiles of which made the plots more attractive to adults; or d) that a combination of two or more of the above was occurring. The fact that significantly higher numbers of male and female *D. planipalpis* were trapped in the untreated than in the treated 'Tobin' suggests that one or both of sequence 'b' or 'c' above were occurring. The untreated 'Tobin' would have been open to early season attack by *D. radicum*, *D. floralis*, or *D. planipalpis*, as well as by a number of associated disease organisms. This may have occurred, but to a lesser extent, in the treated varieties. The observation by McDonald (1985) that 'Tobin' is more susceptible than 'Westar' to damage by *D. radicum*, may also be suggested for *D. planipalpis* from my data. The data reported in Chapter 2 and in the present chapter suggests that *D. planipalpis* may be of greater importance as a canola-infesting species than had been previously thought.

Hough-Goldstein and Bassler (1988) found *D. platura* to be attracted to decay organisms, such as bacteria, for oviposition. Harmon et al (1978) found that treatment of squash seeds with thiram or captan actually increased oviposition by *D. platura*. This was attributed to the elimination of competing fungal organisms by the fungicide, which resulted in an increase in bacteria around the root area. Significantly higher levels of *D. platura* were taken in 'Tobin' plots treated with a carbathiin and thiram seed treatment than in untreated 'Tobin' plots on July 20th (Figure 11B). This could have been due to an increase in bacteria in the Vitavax-treated plots during that time. Significantly higher numbers of female *D. platura* were observed between some treated varieties as well. Treated 'Tobin', for example, had significantly higher *D. platura* captures than 'Westar', which was also observed for male *D. planipalpis* in 1990 (Figure 10A). Since *D. platura* is a secondary pest, the higher levels in 'Tobin' may be associated with a higher level of root maggot feeding by primary species such as *D. radicum*, *D. floralis* and *D. planipalpis*.

My results, although preliminary, indicate that some *Delia* species adults may exhibit preferences for certain varieties of canola. This is the first evidence for varietal preferences in canola by *D. planipalpis* and *D. platura*. Further work, however, is required to confirm the significant findings reported here (Figures 10 and 11, respectively for *D. planipalpis* and *D. platura*), and to determine if varietal preferences also exist for *D. radicum* and *D. floralis*, as suggested by other authors (McDonald, 1985; and Dosdall, personal communication). Further work is also needed to determine if varietal preferences change over the growing season. These studies, unfortunately, are beyond the scope of this project.

A complete understanding of varietal preferences by the *Delia* species complex identified in the Peace River Region (Chapter 2), would lead to increased options for root maggot management. For example, trap crops of a more susceptible canola variety (e.g. 'Tobin') could be planted around a less susceptible main crop variety (e.g. 'Westar') to dilute damage in the main crop. The data here indicate that the trap crop could possibly be made even more attractive by withholding the seed treatment, as was observed with untreated 'Tobin'. An understanding of varietal preferences could also be used in developing more resistant varieties, through conventional breeding programs, or through biotechnology.

CHAPTER 4

TRAP COMPARISON AND COLOR:

INTRODUCTION:

Traps are used to sample insect populations when information is required for chemical, IPM or biological control programs, and as a control mechanism for some insect pests, such as for mass trapping of thrips in greenhouses. Interest in trapping to control or monitor populations of insects has been stimulated by the isolation of semiochemical attractants and by improvements in design.

Traps used for monitoring organisms can be separated into two categories: those used for basic biological and ecological studies, such as when specimens are needed for identification, species diversity or life histories; and those used for monitoring populations of harmful or beneficial organisms in applied IPM programs. Insect trapping methods include semiochemical traps baited with pheromones, kairomones and allomones, along with the more traditional physical, interception, pitfall, suction, color and sticky traps.

A numerical relationship between the values obtained by monitoring techniques for pests and the damage they cause is an essential element in the establishment of a pest management program. Once such information becomes available it should be possible to estimate from just one set of data the numbers of pests likely to be caught in any of the current types of traps.

TRAPPING *DELIA* SPP.:

D. radicum

Yaman (1960) used "catching boxes" to study the effect of naturally occurring biological controls of *D. radicum* populations. These traps consisted of wire-gauze covered boxes, in which he placed a known number of plants with soil around their root systems. He also used "cone cages" which were placed over randomly chosen plants to collect emerging adults. Eckenrode and Chapman (1972) used baited cone screen traps, of 1m diam at the base and 20-22cm high, to study *D. radicum* population trends in cabbage fields.

Hawkes (1972), used water traps with .05% nicotine and 0.2% Teepol (detergent) solutions with white or yellow traps, to study the diurnal periodicity of *D. radicum*.

Finch and Skinner (1982) used yellow water traps baited with allyl isothiocyanate. The addition of this volatile glucosinolate-derived kairomone significantly increased catches of *D. radicum* in cauliflowers.

To study the relative abundance of *D. radicum* in Alberta, Griffiths (1986b), used bowl traps filled with Galts solution (an equal mixture of glycerol and water saturated with picric acid).

Other studies have used sticky traps for sampling *D. radicum*. Finch and Collier (1989) used sticky traps each consisting of a 10cm x 20cm Perspex® acrylic sheet coated with Tangletrap®. These traps were placed in vegetable crops at different angles to evaluate attractiveness to various *Delia* spp. in England. *Delia* were found to prefer to land on horizontal surfaces. The four *Delia* species captured in their study were *D. antiqua*, *D. floralis*, *D. platura* and *D. radicum.*

D. floralis

Griffiths (1986c) used yellow or white pan traps to monitor *D. floralis* in northern Alberta, and did not find pronounced differences in captures between the yellow or white pans, probably because the Galts solution added to the bowl traps appeared yellowish against a white background.

D. planipalpis

Little information is available in the literature regarding trapping methods for *D. planipalpis*. Griffiths (1986c) captured adults in yellow bowl traps at Berwyn, in the Peace River Region.

D. platura

D. platura has been trapped using sticky traps and pan traps. Kring (1968) trapped seed corn maggots in tobacco fields on colored sticky stakes. Griffiths captured *D. platura* in white and yellow bowl traps during studies on *D. radicum* in Alberta (1985, 1986a).

COLOR PREFERENCES:

Color vision and behavior studies have shown that color vision occurs in members of the Hymenoptera, Diptera, Coleoptera, Lepidoptera, Neuroptera, Heteroptera, Homoptera and Orthoptera. The insect-visible spectrum generally lies between 350-650nm

(Chapman, 1976). Color preferences in insects may be due to preferred sources for egg laying or feeding. Kring (1968) attributed color responses *Delia* spp. to the corresponding color of flowering host plants.

Three attributes define a color, specifically, hue, saturation and intensity (Moericke, 1969). Work by Vernon and Bartel (1985) found that color selection by the onion fly, *D. antiqua* (Meigen) was greatly influenced by the hue, saturation, and intensity of color sticky traps. Vernon and Gillespie (1990) found that reducing the reflectance intensity of attractive hues by the addition of black resulted in a linear reduction in the number of western flower thrips, *Frankliniella occidentalis* (Pergande) trapped. Desaturating the attractive hues by the addition of white, also resulted in a decreased response. Vernon and Borden (1983) found spectral preferences in *D. platura, D. antiqua,* and *D. radicum*, using sticky cardboard of selected hues.

D. radicum

D. radicum has been shown to be attracted to a number of colors, including yellow (Griffiths, 1985; Vernon and Borden, 1983), blue (Vernon and Borden, 1983), violet (R. S. Vernon, personal communication) and white (Griffiths, 1985, Vernon and Borden, 1983). From these tests, it appeared that yellow was the most attractive (R. S. Vernon, personal communication) and traps used for monitoring this pest are often painted yellow (Hawkes, 1972; Griffiths, 1985). Griffiths (1985) found white and silvery grey sticky traps did not attract as many *D. radicum* as yellow. The preference for yellow, however, was not apparent in my study in early July when the canola crop was in full bloom.

Work has shown that non-UV reflecting white traps are attractive to *D. radicum*, whereas UV reflecting white is not (R.S. Vernon, personal communication). This has also been demonstrated for the onion fly, *D. antiqua* (Judd, 1986).

D. floralis and *D. planipalpis*

References to the color preferences of *D. floralis* and *D. planipalpis* color preferences were absent from the literature reviewed. These species however, were collected in the yellow pan traps used by Griffiths (1986b, 1986c).

D. platura

D. platura and *D. florilega* are attracted to blue (Vernon and Borden, 1983), violet (R.S. Vernon, personal communication), white (Kring, 1968), and gray (Vernon and Borden, 1983). Kring (1968) studied the color preferences of *Delia* spp. in tobacco fields. White and yellow captured significantly more flies than black, orange, and red. Princess blue and clover green captures were intermediate in numbers.

Vernon and Borden (1983) found *D. platura* to have a marked preference for gray and also had consistent responses to yellow, white, and blue colored cards. In the same study black, red, pink, orange and often green were not attractive.

D. antiqua

D. antiqua, the onion fly, is attracted to similar colors as *D. platura*, responding to blue, violet and white (Vernon and Bartel, 1985; Vernon, 1986). In general, colors with peak reflective wavelengths between 400 and 470nm, at or above 30% reflectance intensity, were most preferred by *D. antiqua* (Vernon, 1986).

White-painted sticky traps are used to monitor *D. antiqua* in a commercial integrated pest management program in British Columbia (Vernon et al, 1989). Although yellow traps are used in other areas such as Ontario for commercial monitoring, yellow has been shown to be inferior to white in attracting *D. antiqua* (Vernon and Bartel, 1985).

COMPARISONS:

The two most common methods used to trap *Delia* species are water pan traps and colored sticky traps. Advantages and disadvantages exist with either technique. Finch and Skinner (1974) found that many factors affect the efficiency of water-traps for capturing *D. radicum*. These factors include color, added attractants, trap height, trap spacing and the age and sex of the populations.

When studying population trends of *D. radicum*, Griffiths (1985) found that sticky traps were unnecessarily time-consuming when removal of large numbers of insects for positive identification were necessary. He considered that the diversity of flies in and around canola fields was too great to be reliably identified and counted on sticky traps. Despite lower precision in identifying *Delia* spp using sticky traps as compared with pan traps, sticky traps are generally preferred as a population monitoring tool in most *Delia* IPM programs (Vernon et al 1989). This is because sticky traps are generally less expensive and easier to service in large scale monitoring programs. With experience, *Delia* spp. identifications can be made with adequate accuracy directly from the traps using a disecting microscope. Sticky traps are also preferred over pan traps in mass trapping programs, such as in greenhouses for western flower thrips and white flies (R.S. Vernon, personal communication).

Four *Delia* species studied by Finch and Collier (1989), notably *D. antiqua, D. floralis, D. platura* and *D. radicum*, preferred to land on horizontal rather than vertical surfaces, indicating that they are likely to be trapped in large numbers in water traps, which should be highly suitable for monitoring adults of all four of the *Delia* species studied here. Pan traps have the added advantage that, unlike sticky traps of the same surface area, they rarely become saturated by the numbers of insects caught. Drawbacks arose with the trapping of beneficial insects such as *Syrphidae.* This could be avoided by using color preferences, where light blue was unattractive to most beneficial insects. Finch (1990) compared six different types of traps used in taking *D. radicum.*

Transferring data collected in one type of trap to another area for interpretation would be very useful when used in IPM. Trapping methods must be effective and comparable with established economic thresholds for control programs.

OBJECTIVES:

a) To determine the relative attractiveness of a number of saturated color hues to species of *Delia* inhabiting canola in the Peace River Region. Variability in species attractiveness to colored traps when colors were presented before and during flowering was also assessed.

b) To determine the relative efficacy of yellow pan traps versus yellow sticky traps in determining *Delia* spp. diversity in canola. This study was conducted during a single growing season to determine if shifts in trap efficacy or in preferences would occur over time.

MATERIALS AND METHODS:

TRAP COLOR PREFERENCES:

Color studies were conducted in a planting of *B. rapa* cv 'Tobin', seeded on June 3, 1990 immediately to the west of the varietal preference plots referred to in Chapter 2 (Figures 2 and 3). Five replicates consisting of five different color traps were established at two different crop stages.

The first study (Study 1) was conducted between June 29 and July 4, during the late rosette stage (2.5-4.0 of growth stage, Campbell and Kondra, 1977) while the second study (Study 2) was conducted between July 13 and July 20 during the early flowering stage (4.1-4.15 of growth stage, Campbell and Kondra, 1977).

The paints were double coated onto white cardboard sheets (4-ply Railroad Board, Domtar Fine Papers, Toronto, Ontario) and cut into 11 x 28cm rectangles. Colors used were obtained from R.S. Vernon

(Agriculture Canada, Vancouver, B.C.). The tested colors were: UV white ((PbCO3)2 x PbOH2) (Carter Chemicals, Montreal, Que., Canada); blue (Cloverdale Paint (CP) and Chemicals, Surrey, B.C., Canada); green (CP 785); yellow (CP 776); and white (CP Alkyd semigloss). Visible reflectance spectra (Figure 12) of the newly-painted color traps were obtained using a Hunterlab Model D-53 Spectra Sensor with a barium sulfate standard.

The rectangles were folded in half to form two-sided traps, 11cm high by 14cm long. The traps were clipped to 1 x 3cm wood stakes which were driven into the ground to an upper height of 30cm. The stakes were placed 1m apart, with 200m between replicates in a linear randomized complete block design. The colored sides were oriented to face N and S, 5° to the south east. The traps were 8m from a grass strip on the west and 8m from the mowed walkway around the varietal preference site (Figure 3).

Identifications of *Delia* spp. were made by R.S. Vernon using the diagnostic keys of Brooks (1951) and Griffiths (1992b). The data were subjected to analysis of variance after transformation (square root of X + 0.5) and where appropriate, were ranked by Duncan's Multiple Range test to a significance level of 0.05.

PAN TRAPS VERSUS STICKY TRAPS:

The pan trap versus sticky trap experiment was established in a *B. rapa* variety demonstration set up by the Canola Council of Canada. The demonstration included 'Tobin', 'Colt', 'Horizon', and 'Parkland', which were replicated 4 times in a randomized block design. The field location was 400m to the east of the varietal preference and color studies (Chapter 2, Figures 2 and 4).

The plots were sown on May 29, 1990, at 8kg/ha, at a depth of 2.5cm. Each variety was replicated four times in 13m x 100m plots (Figure 4). A total nutrient package of 103kg/ha of N, 55kg/ha of P, 290kg/ha of K and 37kg/ha of S was available through fertilizer application and soil availability.

The trap comparison study consisted of paired pan and sticky traps placed at two locations in the 'Tobin' variety plots only (Figure 4). The paired traps were 9m from the east and west ends of the 'Tobin' plots, with traps 5m apart and 4m inside the north and south edges of the 'Tobin' plot. Pan traps were as described in Chapter 2. Sticky traps were the same as the yellow sticky traps in the color studies described above. Traps were clipped to garden laths and set at a height of 30cm. Weekly pan trap collections were as described in Chapter 2. The sticky traps were picked up and replaced on the same dates. Traps were marked for date, N or S face and replicate number. Sticky traps were stored for *Delia* species identification in field collection boxes obtained from R.S. Vernon.

The data obtained from the trap comparison study were subjected to analysis of variance (ANOVA) on square root transformed data.

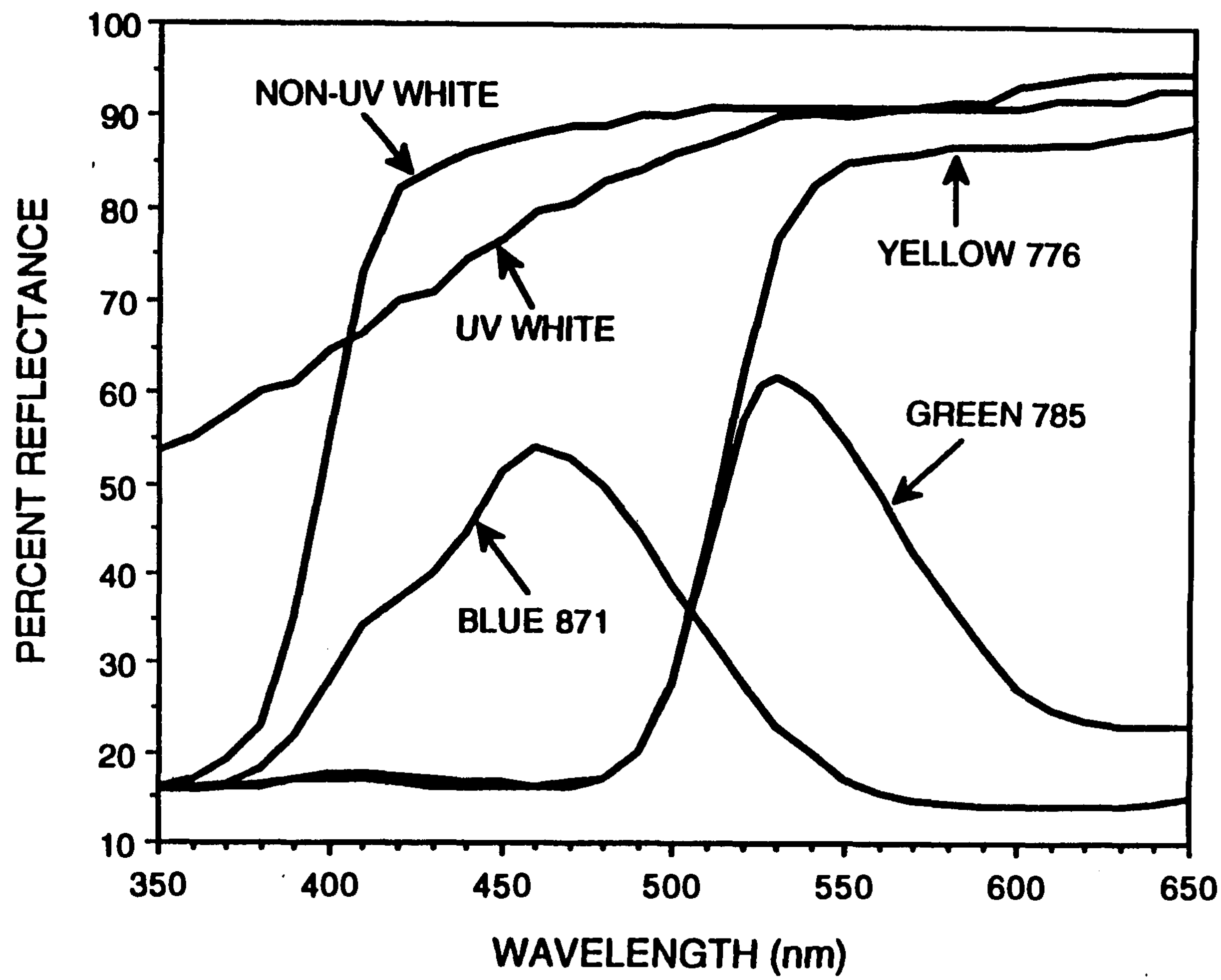


Figure 12. Spectral reflectance curves of cardboard sticky traps painted UV white, white blue (871), green (785), and yellow (776).

RESULTS AND DISCUSSION:

TRAP COLOR PREFERENCE:

The color traps set out on June 29 (Study 1) were picked up on July 4. Weather during that period was normal for this area with scattered thunder showers occurring on July 1 and 2, but heavy rains did not fall in the plot area. Winds were average (175km/day), and daily temperatures averaged 12°C. Sunlight hours averaged 8.5 h/day (excepting July 2 with 0.2h). The canola was mostly in the late rosette stage, with a few plants bolting up to 25cm in height, by July 3. The predominant background color was olive green mixed with grey patches of soil. The green 785 trap was slightly lighter in color than the crop.

The color traps for Study 2 were placed in the field on July 13 and were picked up on July 20. The weather during this study was also normal, with temperatures averaging 14°C and winds averaging 185km/day. Thunderstorms on July 16 (18.5mm) and on July 17 (13mm) did no damage to traps. Sunlight hours averaged 11.3h/day. The canola crop height averaged 50cm and was flowering throughout this study. The background color of the flowers was yellow, a similar shade to the trap color, yellow 776, mixed with the olive green of the crop foliage.

Total numbers of *D. radicum* and *D. planipalpis* captured were low compared with *D. platura* and *D. floralis*. Relative numbers of male and female *Delia* spp. captured in the color studies conducted in 1990 are shown, respectively, in Figures 13 and 14. During Study 1, higher captures of *D. floralis* and *D. platura* than of *D. radicum* and *D.*

planipalpis were observed. This trend continued in Study 2, but somewhat larger numbers of *D. radicum* females were captured at this time.

In general, trap captures consisted almost entirely of the four *Delia* spp. being studied. Other species of flies were caught on the traps, such as *Muscidae* and *Dolichopodidae*, but these were easily identified and not included in totals. Unknown or unidentifiable *Delia* spp., which accounted for less than 1% of the flies captured, were also excluded.

D. radicum

Numbers of *D. radicum* males and females captured on the color traps were very low in both studies (Figures 13 and 14), however, significant preferences to certain colors were observed in some cases. In color Study 1, against a green, non-flowering background, white traps caught *D. radicum* females in significantly greater numbers than UV white, green or yellow traps. Color preferences were not observed in *D. radicum* males (Figure 15). In color Study 2, against a yellow flowering background, numbers of females were significantly greater on white and blue traps than on UV white, green or yellow traps. Male captures were significantly higher on yellow than on blue traps (Figure 15).

Overall, the colors most preferred by *D. radicum* were yellow (for males in Study 2), white and blue (for females in both studies). These data support the findings of Vernon (personal communication),

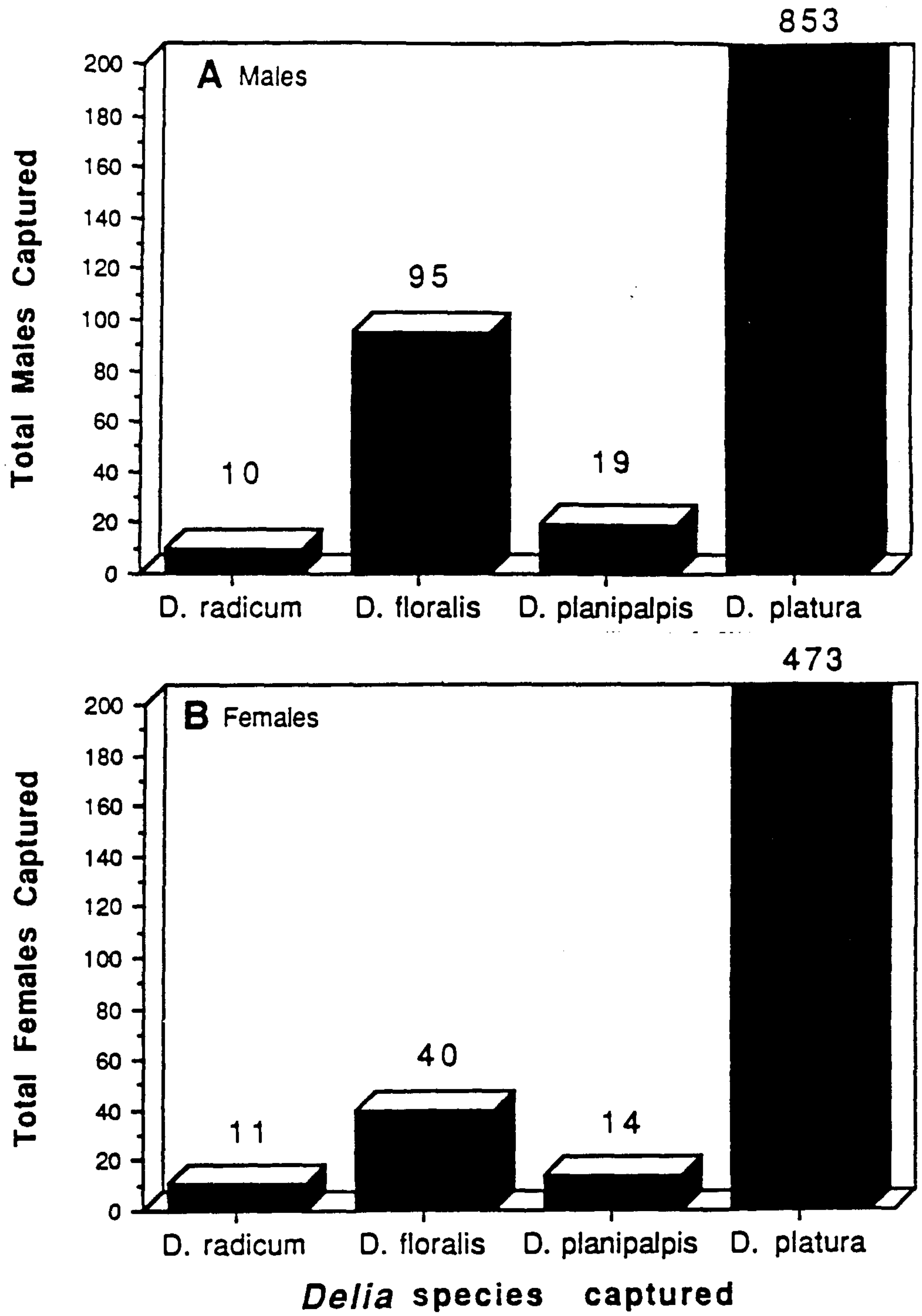


Figure 13. Relative total numbers of four *Delia* species captured on 5 differently colored sticky traps from June 29th - July 4th, 1990 (Study 1), in a field of 'Tobin' canola in the late rosette stage.

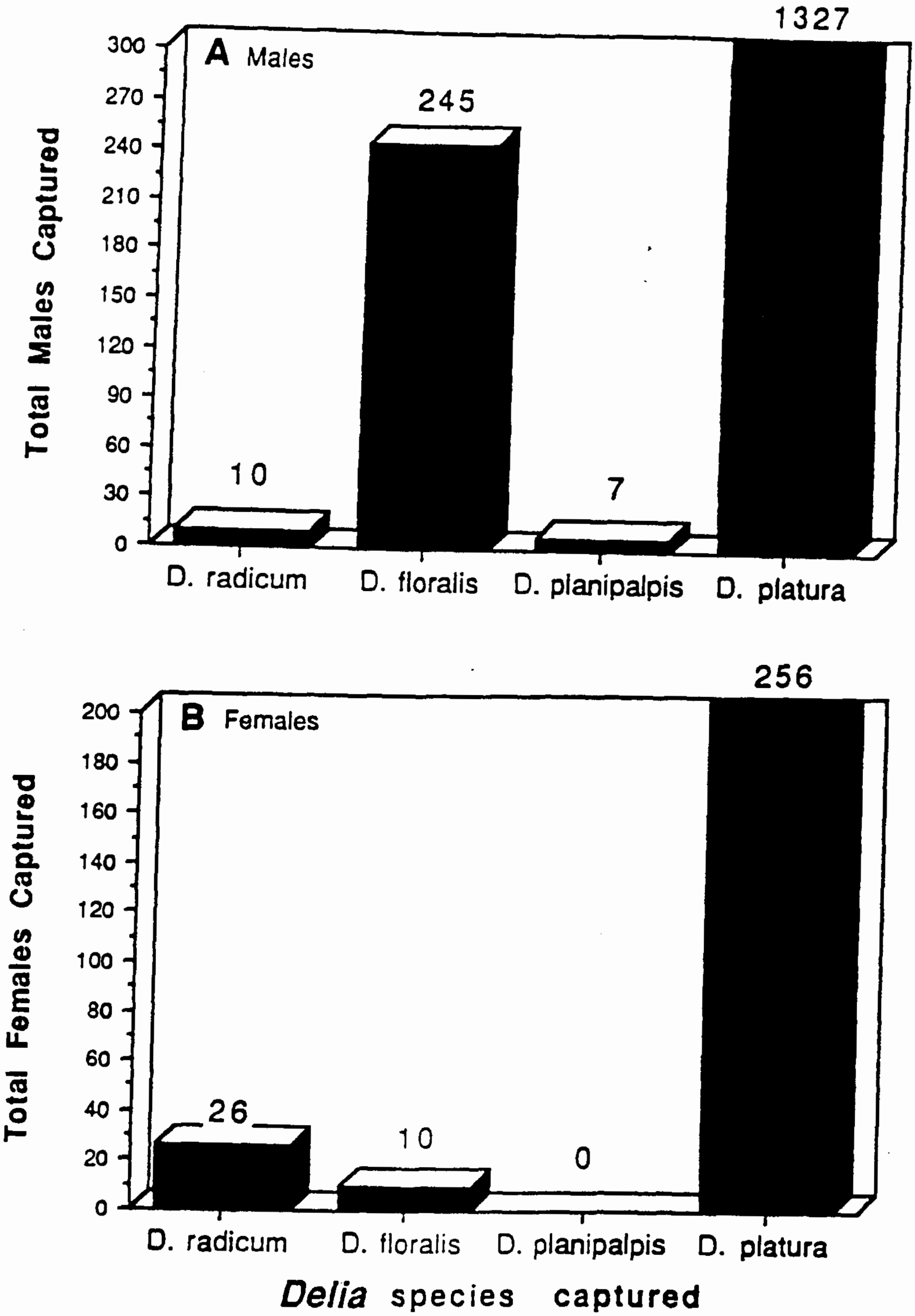


Figure 14. Relative total numbers of four *Delia* species captured on 5 differently colored sticky traps from July 13th - July 20th, 1990 (Study 2), in a field of 'Tobin' canola in bloom.

that white, yellow and blue are the preferred trap colors for *D. radicum*.

D. floralis

Total numbers of *D. floralis* captured on the color traps were greater for males than females in both studies (Figures 13 and 14). This was especially pronounced in study 2 (Figure 14), when only 10 females were caught, but 245 males.

In Study 1, males were significantly more attracted to white traps than to UV white, green or yellow traps (Figure 16). Blue was also preferred over green and UV white. Females were significantly more attracted to yellow and white than to the other colors. These data show that differences in color attraction may exist between male and female *D. floralis* at certain times during the growing season.

In Study 2, *D. floralis* males were significantly more attracted to yellow than to the other colors tested. Green was preferred over white, blue and UV white. For males, the data from Studies 1 and 2 show that differences in color preference occurred when traps were presented against a green, non-flowering background versus a yellow flowering background. No significant differences in trap catch were observed for females during Study 2, probably owing to the low numbers captured.

This is the first documented work on *D. floralis* color attraction of which I am aware. Overall, colors significantly preferred by one or both sexes of *D. floralis* in one or more of the 2 studies were yellow,

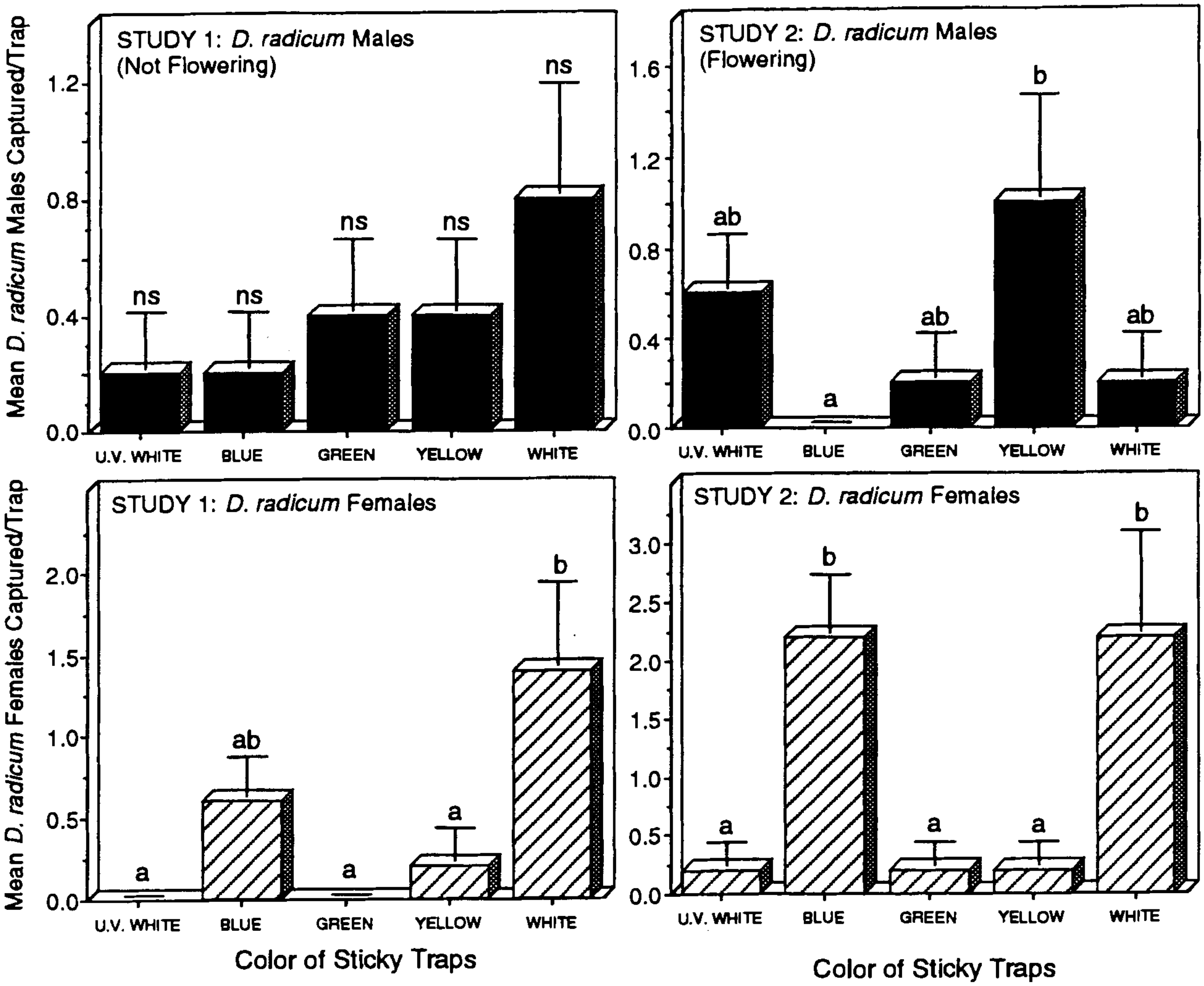


Figure 15. Mean captures (with standard error bars) of *Delia radicum* males and females on 5 differently colored sticky traps in 5 replicates in a field of canola (*B. rapa* cv 'Tobin') for two study periods in 1990: Study 1 was conducted in canola in the late rosette stage (June 29th-July 4th) and Study 2 with canola in bloom (July13th-July20th). Mean captures with the same letter are not significantly different at $P < 0.05$ (DMR test).

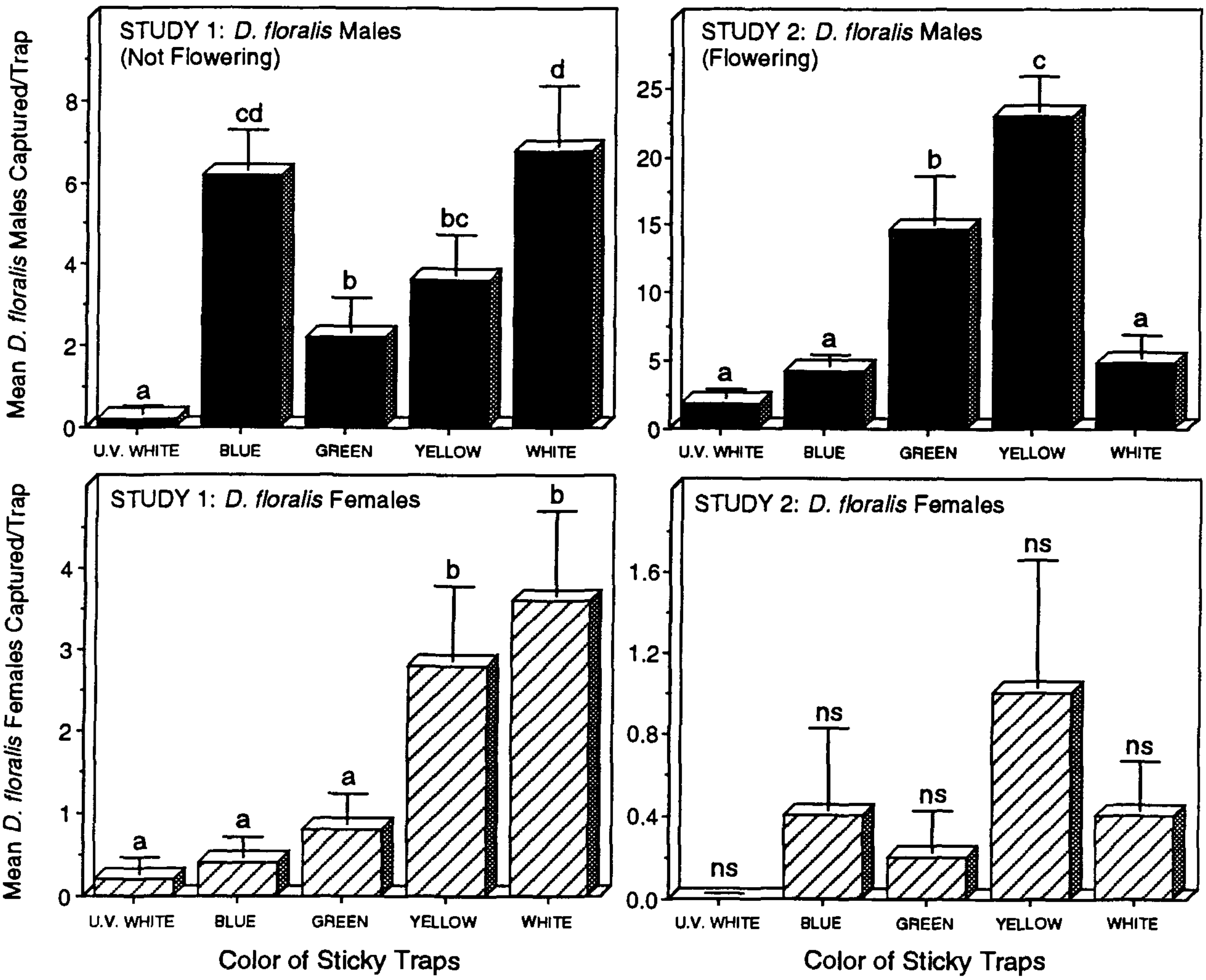


Figure 16. Mean captures (with standard error bars) of *Delia floralis* males and females on 5 differently colored sticky traps in 5 replicates in a field of canola (*B. rapa* cv 'Tobin') for two study periods in 1990: Study 1 was conducted in canola in the late rosette stage (June 29th-July 4th) and Study 2 with canola in bloom (July13th-July20th). Mean captures with the same letter are not significantly different at $P < 0.05$ (DMR test).

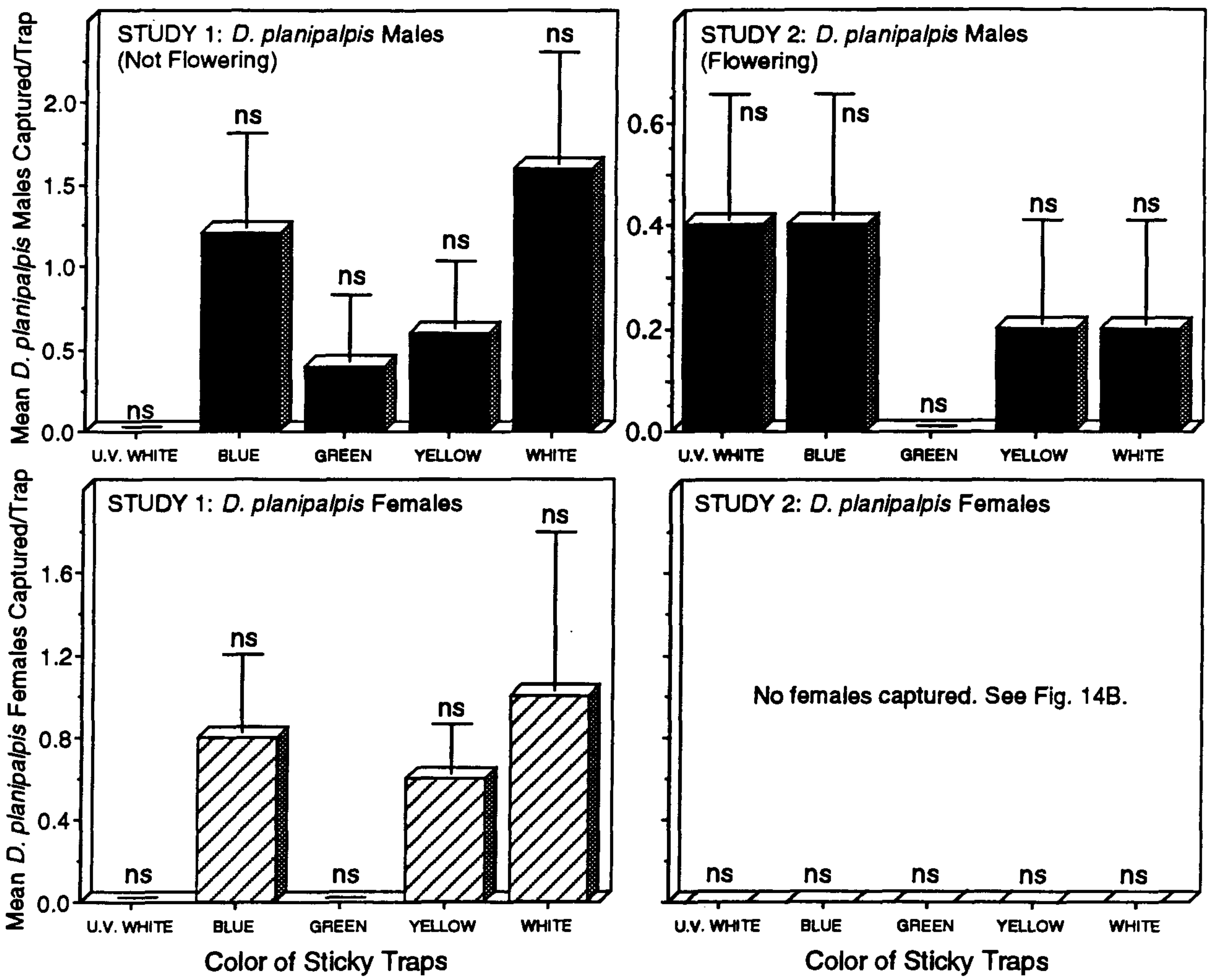


Figure17. Mean captures (with standard error bars) of *Delia planipalpis* males and females on 5 differently colored sticky traps in 5 replicates in a field of canola (*B. rapa* cv 'Tobin') for two study periods in 1990: Study 1 was conducted in canola in the late rosette stage (June 29th-July 4th) and Study 2 with canola in bloom (July13th-July20th). Mean captures with the same letter are not significantly different at $P < 0.05$ (DMR test).

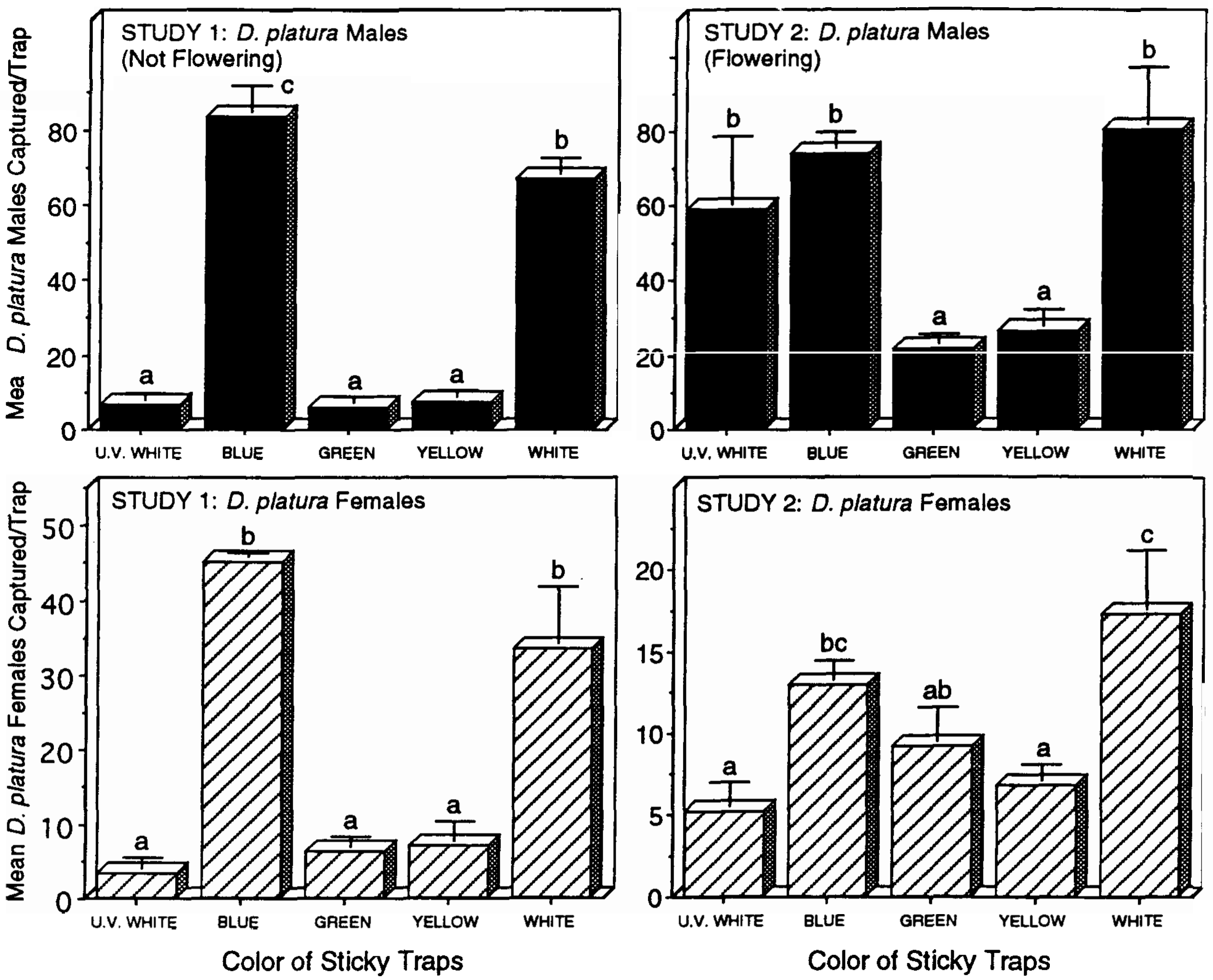


Figure 18. Mean captures (with standard error bars) of *Delia platura* males and females on 5 differently colored sticky traps in 5 replicates in a field of canola (*B. rapa* cv 'Tobin') for two study periods in 1990: Study 1 was conducted in canola in the late rosette stage (June 29th-July 4th) and Study period 2 with canola in bloom (July13th-July20th). Mean captures with the same letter are not significantly different at P < 0.05 (DMR test).

white, blue and green. With the exception of green, these color preferences are similar to those of *D. radicum*.

D. planipalpis

Numbers of *D. planipalpis* males and females captured on the color traps were low in both studies (Figures 13 and 14). Significant color trap preferences were not observed for males or females in either study (Figure 17).

D. platura

D. platura was the predominant species captured in both color studies (Figures 13 and 14).

Males significantly preferred blue over all other colors in Study 1, and white was preferred over UV white, green and yellow (Figure 18). Similar color preferences were observed in Study 2, with the exception that UV white was equal to blue and white in attractiveness.

Color preferences in females were similar to those in males in both studies, except that UV white was not attractive in Study 2. Yellow was not a preferred color by either sex in either study.

Overall, white and blue were the colors preferred by *D. platura* in these studies. My work verifies unpublished work by Vernon (personal communication), who found that blue 871, violet and white, but not yellow 776 were preferred colors for *D. platura*. These data suggest that color attraction in *D. platura* is similar to color attraction in *D. antiqua*, which also responds to blue 871 and white, but not to yellow 776 (Vernon et al, 1985; Vernon, 1986). The data, however, conflict somewhat with those of Kring (1968), who found that *D. platura* preferred sticky stakes painted yellow or white, and were less attracted to blue. There were a number of differences between my study and that of Kring, however, which may account for the differences in color preference observed. Aside from the fact that the paints used were different between the studies, the blue used by Kring was quite dark, with a peak reflectance of <20%, in contrast to blue 871 with a peak reflectance of 53% (Figure 12). Vernon (1986) found that diluting blue 871 with black to produce shades of blue with peak reflectance <30%, significantly reduced the attractiveness of blue sticky traps to *D. antiqua*. Since *D. platura* and *D. antiqua* appear to respond to similar colors, *D. platura* may also respond less strongly to dark shades of blue. The white traps used in both studies were highly attractive to *D. platura*. Reasons for the difference in attractiveness of yellow to *D. platura* between the present study and that of Kring (1968) are not known.

PAN TRAPS VS STICKY TRAPS:

During the summer of 1990, the use of pan traps and sticky traps showed some desirable and unfavorable characteristics of these common trapping methods.

With respect to pan traps, a number of disadvantages were encountered. Early in the season before the crop canopy closed in, rain splashed soil into the pan traps, obscuring much of the yellow color. Later in the season, petals dropped from the canola contaminated some of the pan's surface. Other insects and animals captured were often a consideration. Mice, spiders, bumble bees, honey bees, flea beetles, moths and thrips were found in high numbers in the traps.

Maintenance of the traps during periods of heavy rainfall was a major concern. Both soil splash and trap overflow might have affected the numbers of *Delia* spp. captured. To service the traps, many contingencies must be prepared for, such as replacement bowls for those cracked in service and installation, replacement fluids such as Galts solution or plain water, specimen transfer apparatus (in this case: jars, screening devices, and squeeze bottles with alcohol) along with markers and labels, all of which must be available at all times.

Advantages of pan traps over sticky traps were observed during insect identification. Specimens were intact and could be easily maneuvered, allowing for thorough examination. The intact specimens could also be prepared for independent identification by other workers.

Sticky traps were easier to produce and maintain, but were less conducive to obtaining intact specimens for positive identification. Difficulty in identifying specimens caught by sticky traps was also observed by Griffiths (1985).

Early in the year, soil blown by strong winds could have obscured the faces of sticky traps making them less attractive. During the summer of 1990, however, this did not occur to a large extent, since the traps were oriented so as not to face the prevailing south west winds. Some soil was collected on the traps, but not enough to obscure the color or reduce their efficacy.

Later in the year, canola petals were blown onto the sticky traps face which caused some obscuration (about 1-2%). Once the crop canopy closed in, plant stems and lateral parts of the canola plants became stuck to the traps. Hand removal of plants close to the trap allowed for normal plant sway without the traps being affected.

At one or more times during the course of the growing season, either pan or sticky traps were effective in capturing *D. radicum* (Figure 19), *D. floralis* (Figure 20), *D. planipalpis* (Figure 21) or *D. platura* (Figure 22). Population trends observed in this study were comparable to the population captures in pan traps reported in Chapter 2.

D. radicum

For *D. radicum*, sticky traps captured significantly more flies than did pan traps in 5 of 10 trapping sessions for males (Figure 19), and on 4 of 10 sessions for females. Pan traps never captured significantly more flies of either sex than did sticky traps, although numbers of females were higher in pans late in the season.

This is the first time that sticky yellow traps and bowl traps have been compared in canola for an entire growing season, and the results observed for *D. radicum* have implications for the findings of other workers. Finch (1990) compared five *D. radicum* trapping techniques, including water traps and sticky yellow traps, and proposed a method for converting *D. radicum* catches using one technique to equivalent catches using any of the other techniques. This, it was argued, could be useful in more rapidly establishing *D. radicum* monitoring programs in new areas using any of the five techniques. The 5-trap comparison study, however, was conducted over a 9-day period in September in England, coinciding with the peak activity of the third flight of *D. radicum*. My data indicates that relative trap catches between pan traps and sticky traps can change during the course of a growing season (Figure 19). This information suggests that the trap catch conversion method proposed by Finch (1990), should have been determined over a complete season. This is important information, since most IPM programs to manage *D. radicum* are conducted early, rather than late in the growing season.

D. floralis

For *D. floralis*, sticky traps captured significantly more flies than did pan traps in 9 of 10 trapping sessions for males, and in 2 of 10 sessions for females (Figure 20). Pan traps captured significantly more females than did sticky traps on July 13.

The male to female ratios of *D. floralis* trapped on yellow sticky traps in the color attraction study and in this study are similar.

As observed with *D. radicum*, greater numbers of female *D. floralis* were caught in pan traps at the end of the season, but the numbers were not significant statistically.

Figure 19. Mean captures (with standard error bars) of *Delia radicum* males (A) and females (B) on vertical yellow sticky traps versus yellow pan traps in 8 replicates in a field of canola (*B. rapa*, cv 'Tobin') for 10 trapping periods in 1990. Bars with an 'S' indicate significantly higher catches than those on the other type of trap on the corresponding inspection date, whereas 'NS' indicates no significant differences.

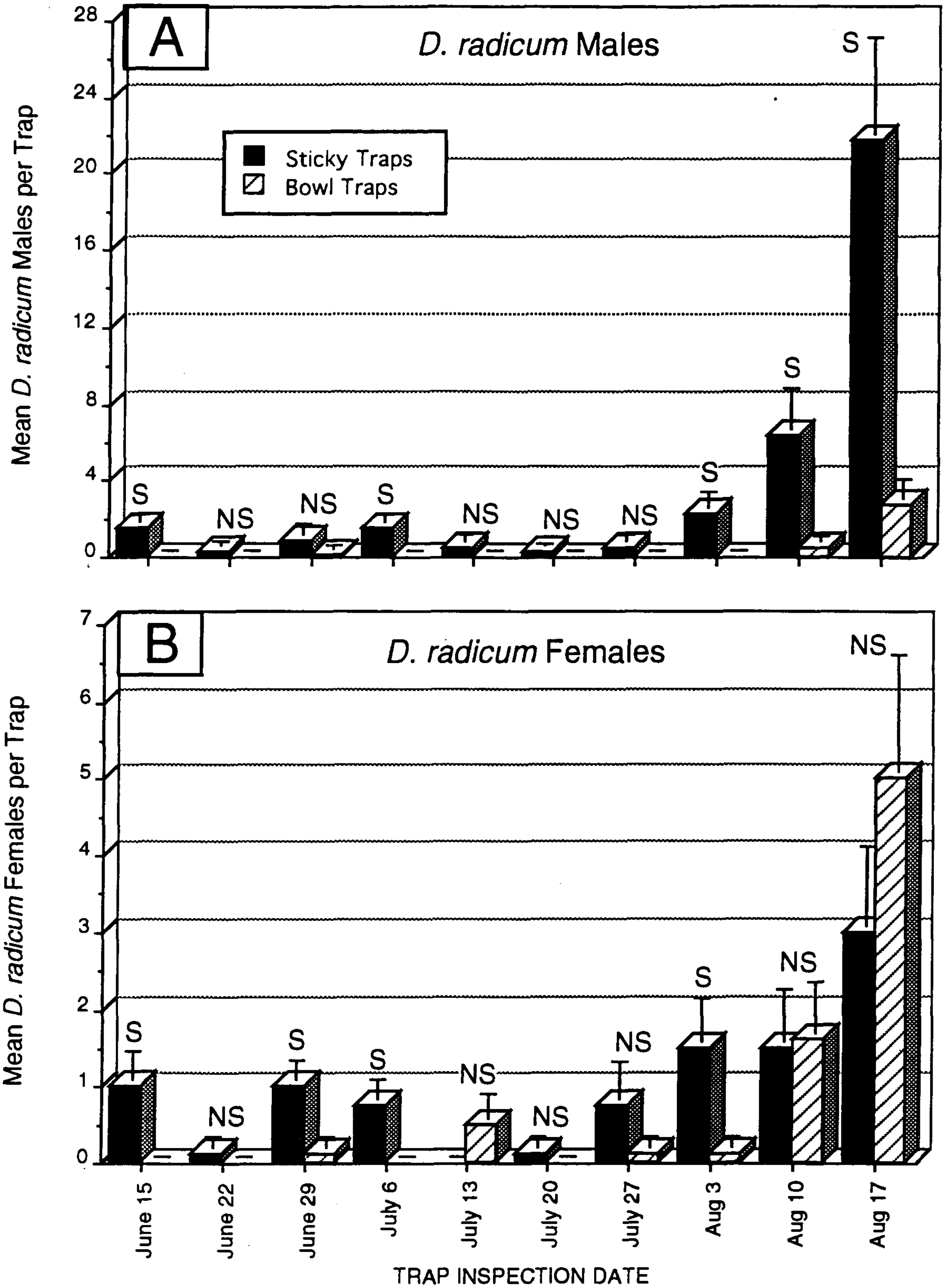

A
D. radicum Males
Mean D. radicum Males per Trap
Sticky Traps
Bowl Traps
0
4
8
12
16
20
24
28
S
NS
NS
S
NS
NS
NS
S
S
S
B
D. radicum Females
Mean D. radicum Females per Trap
0
1
2
3
4
5
6
7
S
NS
S
S
NS
NS
NS
S
NS
NS
June 15
June 22
June 29
July 6
July 13
July 20
July 27
Aug 3
Aug 10
Aug 17
TRAP INSPECTION DATE

Figure 20. Mean captures (with standard error bars) of *Delia floralis* males (A) and females (B) on vertical yellow sticky traps versus yellow pan traps in 8 replicates in a field of canola (*B. rapa*, cv 'Tobin') for 10 trapping periods in 1990. Bars with an 'S' indicate significantly higher catches than those on the other type of trap on the corresponding inspection date, whereas 'NS' indicates no significant differences.

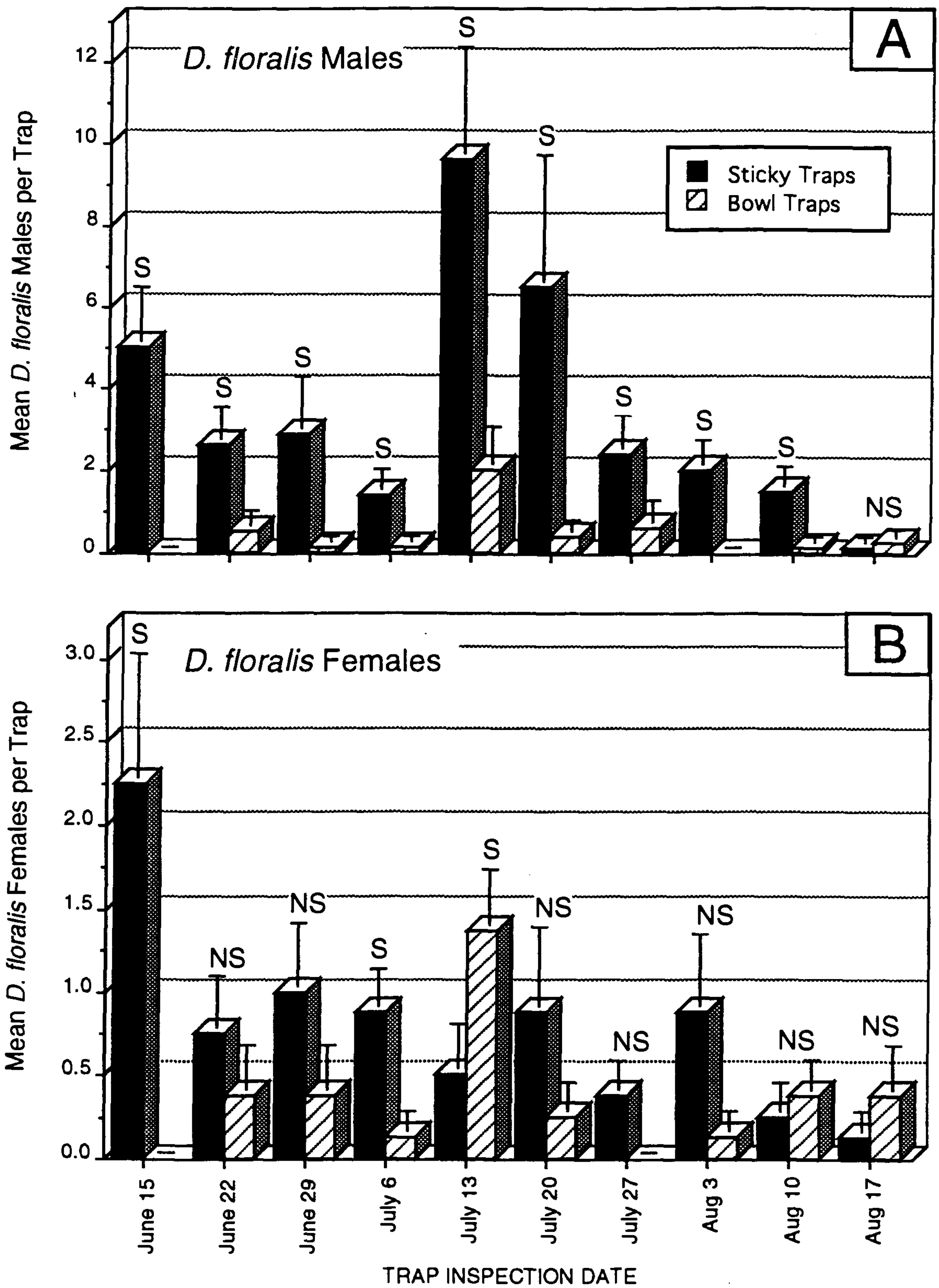

A
D. floralis Males
Mean D. floralis Males per Trap
0
2
4
6
8
10
12
Sticky Traps
Bowl Traps
S
S
S
S
S
S
S
S
S
NS
B
D. floralis Females
Mean D. floralis Females per Trap
0.0
0.5
1.0
1.5
2.0
2.5
3.0
S
NS
NS
S
S
NS
NS
NS
NS
NS
June 15
June 22
June 29
July 6
July 13
July 20
July 27
Aug 3
Aug 10
Aug 17
TRAP INSPECTION DATE

Figure 21. Mean captures (with standard error bars) of *Delia planipalpis* males (A) and females (B) on vertical yellow sticky traps versus yellow pan traps in 8 replicates in a field of canola (*B. rapa*, cv 'Tobin') for 10 trapping periods in 1990. Bars with an 'S' indicate significantly higher catches than those on the other type of trap on the corresponding inspection date, whereas 'NS' indicates no significant differences.

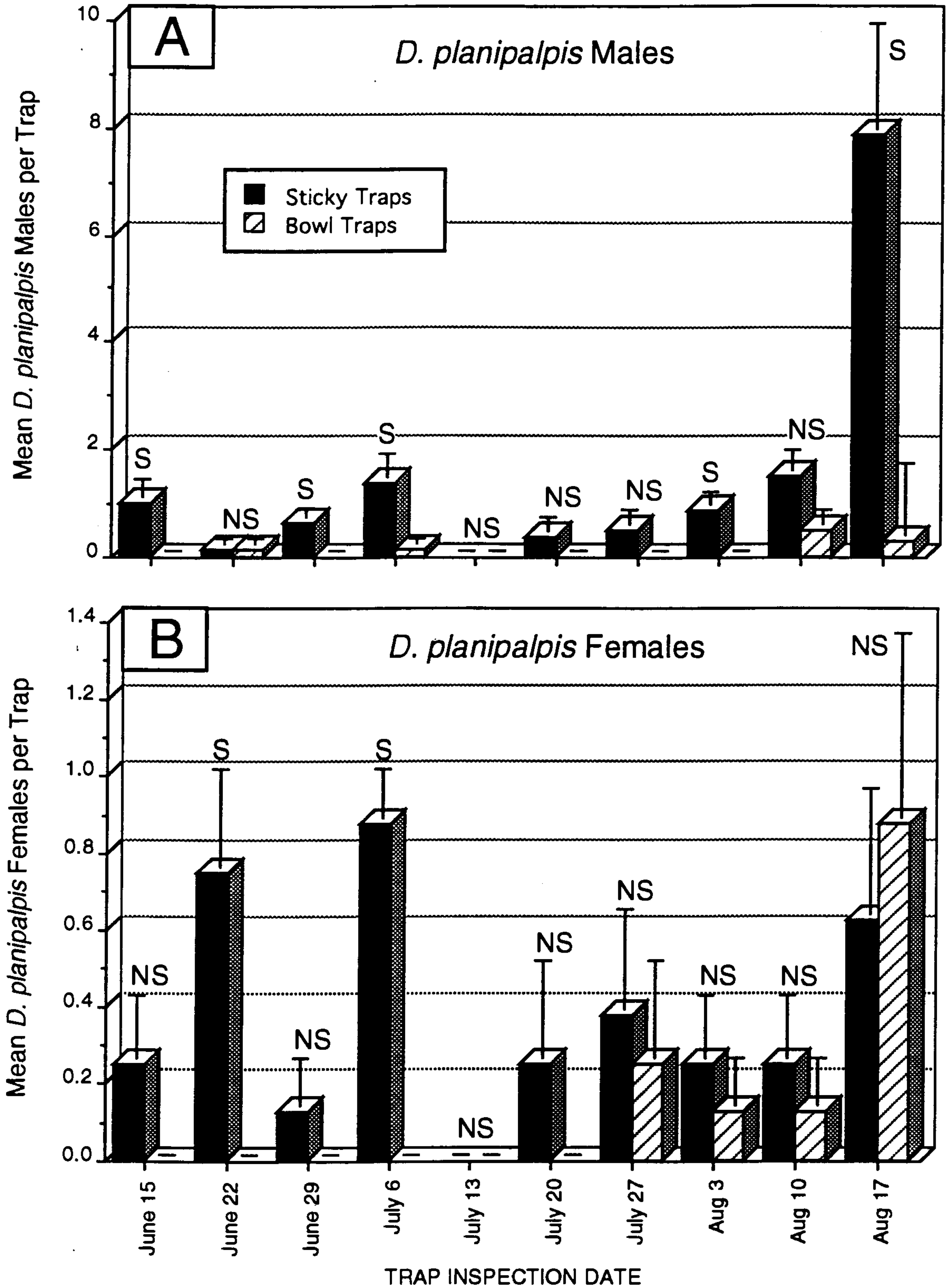
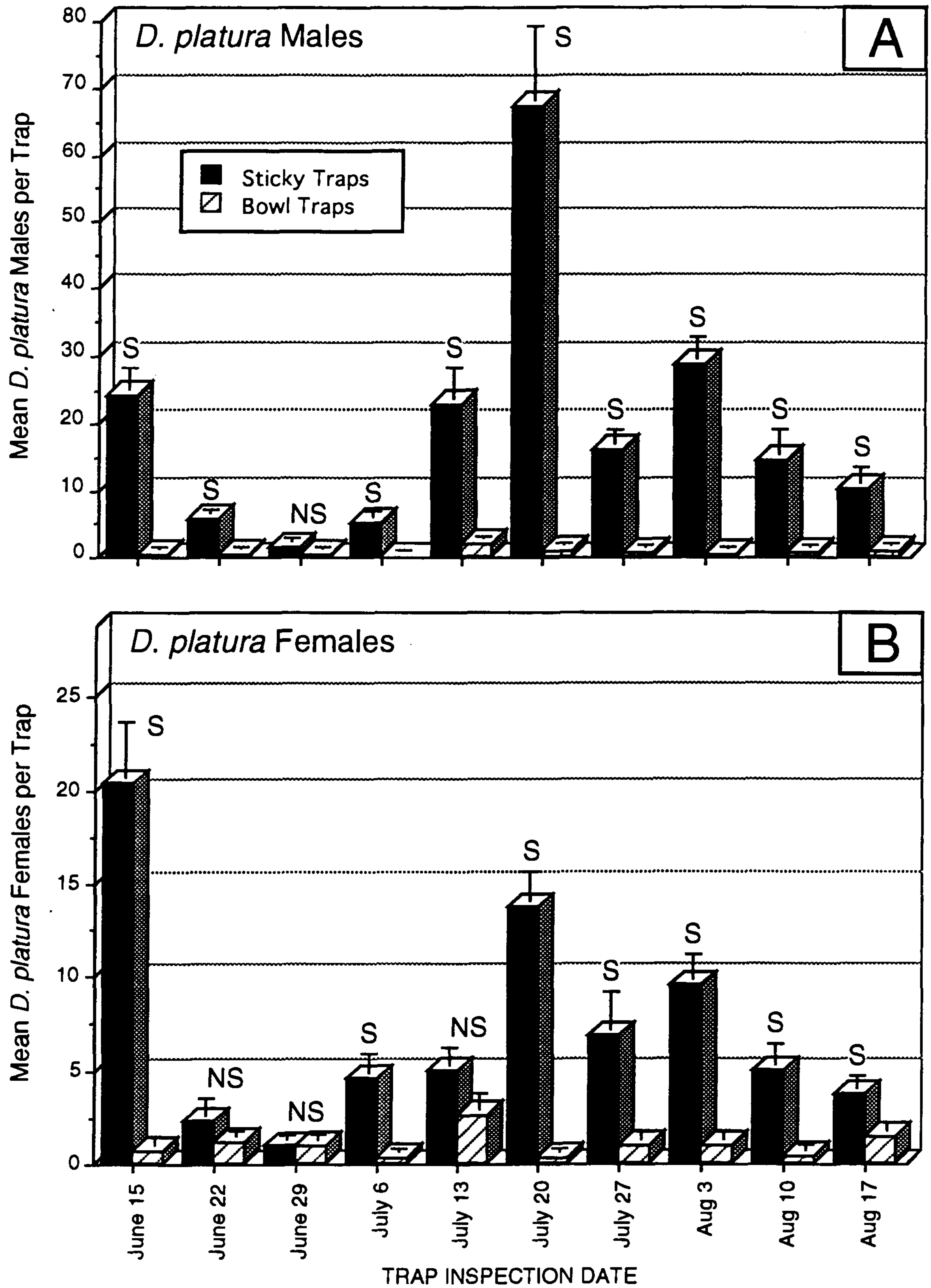

A
D. planipalpis Males
Sticky Traps
Bowl Traps
Mean D. planipalpis Males per Trap
10
8
6
4
2
0
S
NS
S
S
NS
NS
NS
S
NS
S
B
D. planipalpis Females
Mean D. planipalpis Females per Trap
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
NS
S
NS
S
NS
NS
NS
NS
NS
NS
June 15
June 22
June 29
July 6
July 13
July 20
July 27
Aug 3
Aug 10
Aug 17
TRAP INSPECTION DATE

Figure 22. Mean captures (with standard error bars) of *Delia platura* males (A) and females (B) on vertical yellow sticky traps versus yellow pan traps in 8 replicates in a field of canola (*B. rapa*, cv 'Tobin') for 10 trapping periods in 1990. Bars with an 'S' indicate significantly higher catches than those on the other type of trap on the corresponding inspection date, whereas 'NS' indicates no significant differences.



D. platura Males
A
Mean D. platura Males per Trap
80
70
60
50
40
30
20
10
0
Sticky Traps
Bowl Traps
S
NS
D. platura Females
B
Mean D. platura Females per Trap
25
20
15
10
5
0
June 15
June 22
June 29
July 6
July 13
July 20
July 27
Aug 3
Aug 10
Aug 17
TRAP INSPECTION DATE

D. planipalpis

For *D. planipalpis*, sticky traps captured significantly more flies than did pan traps in 5 of 10 trapping sessions for males, and in 2 of 10 sessions for females (Figure 21).

Pan traps never captured significantly more flies of either sex than did sticky traps, although numbers of females were higher in pan traps late in the season.

D. platura

Sticky traps captured significantly more *D. platura* than did pan traps in 9 of 10 trapping sessions for males and in 7 of 10 sessions for females (Figure 22). Bowl traps never captured significantly more flies of either sex than did sticky traps. Unlike the other *Delia* species, female *D. platura* were not captured in greater numbers in bowl traps later in the season.

CONCLUDING DISCUSSION:

The data reported here and by other workers shows that blue and white are preferred by *D. radicum*, *D. floralis*, and *D. platura* (Figures 15-18). Yellow was also preferred by *D. radicum* and *D. floralis*, with attraction by *D. planipalpis* being uncertain from the data. Although yellow was not a preferred color for *D. platura* (Figure 18) high numbers of both males and females were still captured by the yellow sticky traps (Figures 13 and 14) and yellow pan traps (Figure 22).

These findings suggest a number of trapping strategies for monitoring or sampling *Delia* spp. in canola. To conduct more comprehensive species diversity studies in the Peace River Region, a combination of sticky traps and pan traps should be used. The trap comparison study showed that pan traps used alone could miss some species at certain times of the growing season. For example, *D. radicum* (Figure 19), *D. planipalpis* (Figure 21) and *D. platura* (Figure 22) were almost absent in pan traps early in the season, when they were readily detected by sticky yellow traps. Pan traps could almost be abandoned in favor of sticky traps, except that intact pan trap specimens for identification and independent verification are desirable.

For sticky traps, white is recommended for catching the greatest numbers of all *Delia* species, and it has the advantage of presenting a contrasting background to the *Delia* flies, which are dark bodied. Blue presents a darker background, which makes identification on the traps difficult. Some species of *Delia*, particularly *D. platura* can be very numerous, and may actually saturate sticky traps in a short time. Saturation of traps with flies reduces trap's effectiveness, makes identification difficult and tedious, and tends to obscure important population trends. To reduce the number of *D. platura* on traps and yet retain levels of the other primary root-feeding *Delia* spp., the color yellow 776 could be used. The same argument for selecting the most appropriate trap color also applies to the pan traps.

In conducting field surveys for *Delia* species in the Peace River Region, traps should be put out in late April or early May. According to the degree-day observations in Chapter 2, a late April or early May trap date would precede the emergence of all *Delia* spp. populations. This start date would also generally precede the planting of canola in the Region, but would be required for examining degree-day development.

If a routine monitoring program for *Delia* spp. was established in conjunction with an IPM program, sticky traps would be preferred over pan traps. Pan traps are not effective enough early in the growing season, are too inconvenient to maintain, and intact specimens are not generally needed for positive identification in ongoing IPM surveys. Depending on the species of concern, either yellow or white sticky traps would be most appropriate as discussed above. Depending on the species involved and the sticky trap design chosen, damage thresholds could be established with some additional work.

CHAPTER 5

GENERAL SUMMARY AND RECOMMENDATIONS FOR FUTURE RESEARCH

Few crops in prairie agriculture in Canada offer a producer the economic return and marketing flexibility of canola. Being a relatively new crop on the prairies, pest management strategies for canola are only now being developed. With current marketing trends favoring high input management with hybrid seed, and excellent marketing flexibility, improved pest management in canola seems justified and possible.

In Chapter 2 of this paper I documented the identity and abundance of *Delia* spp. captured over one growing season in canola in the Peace River Region, and compared those findings to degree-day accumulations in that year. My results would benefit from more trapping data to ascertain degree-day models for the four *Delia* species, together with an overall study designed to evaluate the impact of each species on canola. Population sampling with emergence cages, supplemented by pan and sticky traps would supply the necessary degree-day information to calculate adult emergence, flight, and egg laying periods in the spring and summer generations of the key *Delia* spp.

The degree-day data suggest that adults of all *Delia* spp. had emerged before June 11 which was the initial trap collection date in my study. Delayed seeding may be an option for control if future studies show that high population emergence occurs before late May or early June. Delayed seeding may be of limited advantage however, because egg-laying for both *D. radicum* and *D. floralis* was found to begin around mid-June in the Edmonton area (Griffiths, 1986a). To reach maturity, *B. rapa* varieties should be planted by June 20, and *B. napus* varieties even earlier. Data indicate that there are limited degree-day accumulations in the fall for development to the pupal stage for a second, or summer generation, of *D. radicum, D. floralis* and *D. planipalpis*. Dosdall (1992) has shown that fall tillage reduces the overwintering survival of pupae of *D. radicum* and *D. floralis*. The limited degree-day accumulations in the fall, and shown here, supports his study.

D. platura populations were trapped in high numbers early in the 1990 growing season. Other researchers have shown that *D. platura* has the potential to be a primary attacker in other crops, but laboratory studies are still needed to evaluate the damage potential of *D. platura* on canola. With high numbers captured in all types of traps early in the season, even as a secondary invader it would cause economic damage in canola if it compounded the attack of primary root feeders like *D. radicum, D. floralis* or *D. planipalpis*.

Chapter 3 documented host preferences in both male and female adults of *D. planipalpis* and *D. platura*. This implies, but does not confirm, that egg laying preferences exist. Population management strategies will present themselves if preferred canola varieties become known. If early seeding is necessary, then a less preferred variety, such as 'Westar', could be used. Preferred varieties could be used as trap crops to attract the second (or summer) generation of adults for oviposition. Mixed cropping systems of field peas and canola are thought to have agronomic advantages. Orientation clues and feeding stimuli used by adult *Delia* may be confused (Lamb, 1989). The possibility of modifying the glucosinolate content of foliage through plant breeding opens up the possibility of developing a canola crop lacking the attractants and feeding stimuli used by damaging *Delia* spp..

The evaluation of trapping methods and color preferences (Chapter 4) will assist in the establishment of monitoring programs for this area. Degree-day information over a number of seasons, supported by field trapping to confirm the *Delia* spp. adult emergence could influence regional planting regimes. Color preferences within *Delia* spp. might prove effective in trapping target species to determine population levels. In time regional specialists could issue general recommendations for canola seeding dates each year.

From my study, the three primary root maggots, *D. radicum*, *D. floralis* and *D. planipalpis,* appear to be codominant in this region. Over the 1990 growing season, the three were taken on sticky traps in a relative abundance of 43.2%, 39.7%, and 17.1% respectively. During the established egg laying period in canola, from mid-June to early July (Griffiths, 1985) the relative abundance was 24.2%, 58.0% and 17.8% respectively. These data are consistent with the relative abundance of *Delia* spp. taken in pan traps and reported in Chapter 2. *D. planipalpis* may contribute more to root damage in canola in the Peace River Region than was previously thought.

Chemical control studies are ongoing. Griffiths (1991a) demonstrated a yield increase of about 50% from *B. rapa* when root maggots were excluded from the crop. Chemical controls of larvae have resulted in a 10% yield increase in *B. rapa*, and 17.8% in *B. napus* varieties (Griffiths, 1992). Adulticides and larvicides for *Delia* spp. in canola appear to be limited in potential, because of their effects on predators and parasites, and the difficulty in timing applications. New formulations of insecticides for seed drill application would need 7-11 weeks persistence to protect the crop from newly-hatched larvae, depending on sowing time.

The color trap preferences reported for the key *Delia* spp. will form the basis of information needed if IPM in canola for root maggots becomes feasible, but at the moment IPM in canola is not an option. Additional knowledge of the damaging *Delia* spp. would also be necessary before using the management options mentioned. Advanced management skills and the benefits gained by employing such tools have not been apparent in prairie crops. An aging farm population, resulting from an exodus of the educated younger generation to high-paying, stimulating, urban jobs, has left the agricultural brain pool on the prairies depleted. Already, tasks for today's producer include: keeping up with current information on fertility and herbicide requirements; and with the latest seeding, harvesting and marketing techniques. Changes will not come easily. IPM will be difficult to sell, because much of prairie agriculture has never readily accepted its concept.

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Appendix 1.

Tables 1-4 show, respectively, mean male and female (± S. E.) *D. radicum*, *D. floralis*, *D. planipalpis* and *D. platura* taken in pan traps in different canola cultivars at various times in 1990. These tables correspond to data presented in Figures 8-11 in Chapter 3.

Table 1. Mean *D. radicum* males (A) and females (B) taken in pan traps in different canola cultivars during 5 trapping intervals in 1990. These data correspond to those shown in Figure 8.

A. Males	Mean *D. radicum* (± S.E.)[1]				
Variety	11/06 - 03/08	10/08	17/08	24/08	31/08
Unt. Tobin[2]	.6 (.3)	.9 (.3)	1.6 (.7)	2.4 (.7)	2.1 (.9)
Westar	.9 (.4)	.0 (.0)	1.1 (.4)	.6 (.3)	3.1 (1.2)
Parkland	.5 (.3)	.8 (.2)	1.4 (.7)	1.1 (.4)	2.1 (.8)
Horizon	.5 (.3)	.5(.3)	2.1 (.8)	1.1 (.1)	1.5 (.3)
Colt	.4 (.2)	.4(.3)	1.1 (.5)	1.6 (.7)	1.8 (.7)
Tobin	.8 (.3)	.6 (.4)	2.4 (.9)	1.8 (.6)	1.6 (.4)
B. Females					
Unt. Tobin	1.7 (.7)	1.6 (.4)	3.5 (.6)	4.8 (1.3)	2.1 (.4)
Westar	1.1 (.4)	.6 (.3)	2.5 (.6)	2.8 (.9)	1.5 (.5)
Parkland	1.3 (.4)	.9 (.5)	2.4 (.5)	3.0 (.9)	1.8 (.6)
Horizon	1.1 (.6)	1.0 (.3)	1.8 (.3)	1.6 (.7)	1.9 (.4)
Colt	1.1 (.4)	.6 (.3)	1.8 (.9)	3.1 (1.1)	2.0 (.4)
Tobin	.8 (.4)	.6 (.3)	2.8 (.9)	3.6 (1.4)	2.0 (.5)

[1]Means of males and females taken in 8 pan traps in each canola cultivar.

[2]Tobin that was not treated with Vitavax seed treatment.

Table 2. Mean *D. floralis* males (A) and females (B) taken in pan traps in different canola cultivars during 2 trapping intervals in 1990. These data correspond to those shown in Figure 9.

A. Males	Mean *D. floralis* (± S.E.)[1]	
Variety	11/06 - 27/07	03/08 - 31/08
Unt. Tobin[2]	1.6 (.6)	.4 (.2)
Westar	1.1 (.7)	.3 (.2)
Parkland	1.6 (.5)	.5 (.2)
Horizon	1.6 (.6)	0.0 (0)
Colt	1.0 (.3)	.1 (.1)
Tobin	1.6 (.4)	.3 (.2)
B. Females		
Unt. Tobin	2.5 (.8)	4.0 (.8)
Westar	1.9 (.5)	1.8 (.5)
Parkland	1.8 (.4)	3.5 (.7)
Horizon	2.8 (.6)	3.1 (.7)
Colt	2.9 (.5)	3.4 (.8)
Tobin	1.6 (.6)	2.5 (.7)

[1]Means of males and females taken in 8 pan traps in each canola cultivar.

[2]Tobin that was not treated with Vitavax seed treatment.

Table 3. Mean *D. planipalpis* males (A) and females (B) taken in pan traps in different canola cultivars during 5 trapping intervals in 1990. These data correspond to those shown in Figure 10.

A. Males	Mean *D. planipalpis* (± S.E.)[1]				
Variety	03/08	10/08	17/08	24/08	31/08
Unt. Tobin[2]	1.0 (.4)	2.3 (1.0)	8.8 (2.7)	4.1 (1.0)	2.0 (.6)
Westar	.8 (.3)	.9 (.3)	.4 (.3)	.9 (.4)	.3 (.3)
Parkland	.9 (.3)	1.4 (.5)	4.1 (1.1)	.6 (.4)	1.1 (.5)
Horizon	.3 (.3)	1.9 (.9)	3.1 (1.0)	1.3 (.6)	1.4 (.6)
Colt	.4 (.3)	1.4 (.7)	1.9 (.5)	1.8 (.6)	1.5 (.5)
Tobin	.9 (.4)	2.9 (1.8)	5.4 (2.5)	2.9 (1.6)	2.0 (.6)
B. Females					
Unt. Tobin	.8 (.2)	.5 (.3)	2.0 (.5)	.9 (.4)	.1 (.1)
Westar	.9 (.3)	.1 (.1)	.3 (.2)	.4 (.2)	.3 (.2)
Parkland	.9 (.4)	.3 (.2)	.5 (.3)	.6 (.3)	.1 (.1)
Horizon	1.4 (.5)	.1 (.1)	1.3 (.5)	.4 (.3)	.0 (.0)
Colt	1.4 (.3)	.5 (.3)	.4 (.3)	.5 (.2)	.5 (.4)
Tobin	1.3 (.3)	.3 (.2)	.3 (.2)	.6 (.5)	.6 (.3)

[1]Means of males and females taken in 8 pan traps in each canola cultivar.

[2]Tobin that was not treated with Vitavax seed treatment.

Table 4. Mean *D. platura* males (A) and females (B) taken in pan traps in different canola cultivars during 9 trapping intervals in 1990. These data correspond to those shown in Figure 11.

A. Males	Mean *D. platura* (± S.E.)[1]								
Variety	11/06	22/06	29/06	13/07	20/07	03/08	17/08	24/08	31/08
Unt. Tobin[2]	5.1 (1.0)	1.1 (.4)	.3 (.2)	4.8 (1.0)	.8 (.3)	1.4 (.3)	1.3 (.3)	.4 (.3)	.5 (.4)
Westar	4.6 (1.5)	1.4 (.8)	.5 (.3)	1.9 (.5)	.5 (.3)	.1 (.1)	.1 (.1)	.3 (.2)	.3 (.2)
Parkland	5.0 (1.8)	1.6 (.5)	.4 (.3)	3.0 (.6)	2.1 (.5)	.6 (.2)	.6 (.2)	.9 (.4)	.1 (.1)
Horizon	4.6 (1.4)	1.5 (.5)	.5 (.3)	2.9 (.6)	.6 (.4)	.8 (.3)	.6 (.5)	.4 (.3)	.4 (.3)
Colt	4.1 (1.6)	2.0 (.6)	.5 (.3)	6.1 (1.4)	1.9 (.8)	1.0(.6)	.9 (.3)	.6 (.3)	.5 (.3)
Tobin	3.9 (1.3)	1.6 (.6)	.3 (.2)	3.5 (.6)	.6 (.3)	1.6 (.4)	.9 (.4)	.6 (.4)	.4 (.3)
B. Females									
Unt. Tobin	6.6 (1.8)	4.6 (1.0)	1.5 (.4)	2.6 (.3)	1.8 (.5)	1.6 (.6)	.8 (.4)	1.5 (.5)	.6 (.4)
Westar	9.3 (2.7)	3.8 (.8)	.9 (.3)	2.3 (.7)	1.8 (.7)	.8 (.3)	.4 (.2)	1.0 (.4)	.1 (.1)
Parkland	9.4 (3.0)	4.0 (.8)	1.8 (.5)	2.5 (.7)	.5 (.2)	1.0 (.4)	.4 (.3)	1.0 (.6)	.4 (.3)
Horizon	11.8 (3.7)	4.1 (.9)	1.4 (.3)	2.9 (.7)	.9 (.4)	.5 (.2)	1.1 (.4)	1.3 (.4)	.9 (.3)
Colt	7.5 (3.1)	3.9 (1.1)	1.9 (.6)	3.4 (1.0)	.5 (.4)	1.1 (.4)	.8 (.3)	2.0 (.7)	.9 (.3)
Tobin	7.1 (2.8)	3.5 (.6)	1.9 (.5)	3.5 (.6)	.5(.3)	1.1 (.3)	.9 (.5)	.8 (.3)	.8 (.4)

[1]Means of males and females taken in 8 pan traps in each canola cultivar.

[2]Tobin that was not treated with Vitavax seed treatment.