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FUSARIUM STALK ROT INCIDENCE IN MAIZE, *ZEA MAYS* L., IN RELATION TO THE EUROPEAN CORN BORER, *OSTRINIA NUBILALIS* (HÜBNER) INFESTATION, GENOTYPE MATURITY AND EASTERN ONTARIO CLIMATIC GRADIENT.

by

François Meloche

Thesis submitted to the
School of Graduate Studies and Research,
University of Ottawa,
in partial fulfillment of the requirements for the
Degree of Doctor of Philosophy

in the Ottawa-Carleton Institute of Biology.

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ABSTRACT

Development of maize, *Zea mays* L., germplasm resistant to the European corn borer, *Ostrinia nubilalis* (Hübner) and *Fusarium* fungal pests has been in progress for more than three decades as a worldwide cooperative effort. Some of the host plant resistance to the European corn borer and *Fusarium* has been attributed to the phytochemical product 6-methoxybenzoxazolinone. However, it has been shown that seasonal weather impacts concurrently on maize development, corn borer and *Fusarium* phenology. It was hypothesized that some of the maize resistance to both pests depended directly on climatological conditions.

In the United States, genotype selection for first generation borer resistance is achieved during June infestations using leaf feeding assessment. In Canada, first selection began at the silk stage of plant development in July. In Eastern Ontario, preliminary studies revealed the presence of three adult flights [June, July (main), and August populations]. Since 1988, leaf feeding by the June and July populations has been found to be negligible even in highly infested areas with the corn borer. Moreover, larval recovery in the stalk in October was found uncorrelated with leaf feeding rating. This suggested that under heavy natural infestation, leaf feeding alone was a poor selection indicator of genotype resistance because of the lack of synchrony between the plant susceptible stage and corn borer phenology.

The second genotype selection is conducted at grain harvest in October by plant dissections. The larval population, number of tunnels and tunnel length in the first 30 cm of the stalk above the soil surface were used to differentiate genotype susceptibility to corn borers. Concurrently, grain moisture was directly correlated with genotype resistance to corn borer. It was hypothesized that selection for host plant resistance was related to borer phenology and behaviour in relation to plant development and climatic conditions.

Fungi encountered comprised *Fusarium moniliforme, F. graminearum, F. sporotrichioides, F. oxysporum, F. avenaceum*, and *F. equiseti*. Two species, *F. moniliforme* and *F. equiseti,* were recovered throughout the season. These fungi were first recovered from pollen caught in the leaf collar sheath. As the leaf sheath of maize is relaxed with plant development, the *Fusarium* contaminated soil and the pollen run down past the ligule by wind, rain splash, and insect movement to settled within the sheath cavity. Undamage pith samples (by the borer) taken at grain harvest showed sporadic tissue contamination by *Fusarium*. Oppositely, as the corn borer larvae migrated downward on the plant, they drilled the collar sheath, the stalk rind and digged galleries in the stalk to feed on the pith tissue to complete their development. Consequently, the larvae and borer tunnels were repeatedly contaminated with *Fusarium*. It was hypothesized that *Fusarium* fungi invaded the stalk, via the contaminated pollen, by entering down into the entrance hole made by the corn borer larva and then contaminating the damaged and senescing pith tissue. It was shown that pith tissues were initially colonized by primary fungi such as *F. equiseti* which initiate pith breakdown; then these fungi were overgrown by more competitive species such as *F. moniliforme* or *F. sporotrichioides*.

Correlation of the stalk rot incidence to genotype maturity and the stalk rot incidence to grain moisture were both negative and significant; indicating that physiological activity during October protected the stalk against fungi infection. It was hypothesized that genotype maturity based on the heat unit rating (given by companies) or grain moisture at harvest (indicator of genotype maturity) were the two common factors related to *Fusarium* stalk rot resistance.

Finaly, the multiple linear regression analysis of *Fusarium* incidence as a function of plant and corn borer parameters showed that the number of corn borer tunnels was negatively correlated to *Fusarium* incidence while tunnel length was positively correlated. It is the amount of damage within the tunnel that increase stalk susceptibility to *Fusarium* because of increase plant stress and accumulation of insect frass which constitutes an adequate *Fusarium* medium. It was hypothesized that tunnel entrance alone did not induce stalk rot, but the total tunnel length increased susceptibility to stalk rot.

Environmental factors influence maize resistance, corn borer biology (voltinism, behaviour) and *Fusarium* outbreak. A model for host plant resistance in maize based on genotype corn heat unit rating, number of tunnels and tunnel length was proposed. This model accounts for 54% to 66% of the variation in *Fusarium* incidence.

RÉSUMÉ

La sélection d'une lignée de maïs, *Zea mays* L., résistante à la pyrale du maïs, *Ostrinia nubilalis* (Hübner) et à la fusariose, *Fusarium*, a débuté il y a environ trente ans par un effort collectif de recherche. Une partie de la résistance à la pyrale et à la fusariose a été attribuée au composé phytochimique, le 6-methoxybenzoxazolinone. Par ailleurs, il a aussi été démontré que les conditions climatiques saisonnières ont un impact sur le développement physiologique de la plante ainsi que sur le développement phénologique de la pyrale et de la fusariose. J'ai émis l'hypothèse que le degré de résistance des lignées aux deux organismes nuisibles était dépendant des conditions climatologiques.

Au Etats Unis, la sélection de lignée de maïs résistante à la pyrale s'effectue en juin par l'évaluation du dommage foliaire. Au Canada, cette première sélection s'effectue au stade d'apparition des soies de l'épi, c'est-à-dire vers la fin juillet. Dans l'est Ontarien, les premières études ont indiqué la présence de trois périodes d'envol des adultes [juin, juillet (population principale) et août]. Mes résultats de recherche ont montré que les dommages foliaires par les populations de juin et de juillet étaient négligeables même dans les régions les plus sévèrement infestées par la pyrale. De plus, le recouvrement de larves dans les tiges de maïs en octobre était indépendant et non corrélé avec les dommages foliaires. Ceci suggère que la sélection basée uniquement sur le dommage foliaire est inappropriée à cause du décalage entre le développement phénologique de la plante (susceptibilité) et la période de ponte de la pyrale.

La deuxième sélection est réalisée au moment où la plante a atteint le stade de pleine maturité en octobre. La compilation du nombre de larves, du nombre de tunnels et la longueur des galeries dans le premier 30 cm de tiges au-dessus du sol a permis de différencier les génotypes quant à leur degré de susceptibilité. Concurremment, le degré d'humidité du maïs-grain a été significativement corrélé avec l'intensité de dommage causé par la pyrale.

Nous avons émis l'hypothèse que la sélection de lignée résistante était reliée au développement phénologique de la pyrale et à son comportement en relation avec le stade de la plante et les conditions climatiques auxquelles elles ont été exposées.

Les champignons que j'ai identifiés incluent: *Fusarium moniliformè, F. graminearum, F. sporotrichioides, F. oxysporum, F. avenaceum* et *F. equiseti*. Deux espèces, *Fusarium moniliforme* et *F. equiseti*, ont été observéstout au long de la saison. Ces champignons ont d'abord été récupérés à partir du pollen qui étaient retenus par la ligule du collier folliaire. A mesure que la plante se développait, la gaine de la feuille se détachait de la tige et les particules contaminées de sols et de pollen descendaient le long de la tige par l'action du vent, de la pluie, et le mouvement des insectes pour s'accumuler à l'intérieur de la gaine. Les tissus intacts étaient peu contaminés par la fusariose alors que le pollen retenu dans le collier foliaire était constamment infecté. La larve de pyrale perce la tige et se nourrit en creusant des galeries dans la moëlle de la tige afin de compléter son développement. Les larves et les échantillons de galeries prélevés étaient fréquemment contaminées par le cjampignon. J'ai donc émis l'hypothèse que le *Fusarium* entrait dans la tige par ruisselement grâce aux orifices faites par la pyrale et qu'ensuite seulement le champignon envahissait les tissus endommagés. Ces tissus étaient tout d'abord colonisés par des espèces peu aggressives tel *F. equiseti* qui initient la dégradation des tissus. Ces champignons sont ensuite remplacés par des espèces plus agressives et compétitives tels *F. moniliforme* et *F. sprorotrichioides*.

La régression linéaire multiple de la maturité de la lignée en fonction du pourcentage de fusariose de la tige, et, la régression linéaire multiple du taux d'humidité du maïs-grain en fonction du pourcentage de fusariose étaient toutes deux négatives. J'ai formulé l'hypothèse que la maturité des lignées (basée sur le nombre d'unités thermiques) et le pourcentage d'humidité du maïs-grain (qui indique le stade de maturité) étaient les deux

principaux facteurs de résistance de la plante hôte à la pyrale et au *Fusarium*.

De plus, l'analyse de la régression linéaire multiple de l'incidence de fusariose en fonction des dommages causés par la pyrale révèle que le nombre d'orifices sur la tige était négativement corrélé avec l'incidence du champignon alors que la longueur des galeries était positivement corrélée. Ceci suggère qu'une simple perforation de la tige, sans dommages notables, n'est pas suffisant pour causer la pourriture de la tige. C'est la combinaison de la perforation de la tige, la destruction de tissus pour formet des galeries, l'accumulation de sciure dans ces dernières et l'augmentation de tissus en état de stress et sénescents qui accoît la susceptibilité à la pourriture fusarienne de la tige.

Les facteurs environmentaux exercent également une influence importante sur le degré de résistance phénotypique du maïs, la biologie de la pyrale (voltinisme, son comportement) et l'épidemiologie de la fusariose. Un modèle de résistance chez le maïs basé sur le nombre d'unités thermiques des lignées, le nombre de galeries ainsi que la longueur des tunnels est proposé. Ce modèle explique de 54% à 66% de la variation dans l'incidence de la fusariose de la tige.

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Chapter 1.

GENERAL INTRODUCTION

Maize, *Zea mays* L., is the second most important crop in the world after rice. In North America, the European corn borer, *Ostrinia nubilalis* (Hübner), is one of its most important insect pests with 50 million dollars of annual losses (Isenhour *et al.* 1987) and among all the disease repertoried in maize culture, *Fusarium* species are by far the most important rotting organisms causing millions of dollars of losses annually (Trenholm *et al.* 1988). Stalk breakage resulting from these two agents is considered the most important problem occurring in modern maize cultivation. Any method of reducing these losses would have considerable economic impact. However, there is great difficulty in distinguishing whether the borer or *Fusarium* is the principal instigator of breakage, and which one is the most important in yield reduction.

Today, entomologists and plant breeders are attempting to identify genetic variation in the degree of tolerance to insects and learn how to incorporate traits, such as early maturity, plant height and stalk strength, concurrently with genotype resistance to insects. Maize improvement is complicated by the current changes in the *Fusarium* complex and borer voltinism as well as behavioural changes associated with changing agronomic practice.

The individual interaction of the corn borer with maize, and of *Fusarium* with maize are well studied; but the tripartite interaction among the fungus, maize, and insect is not as well documented.

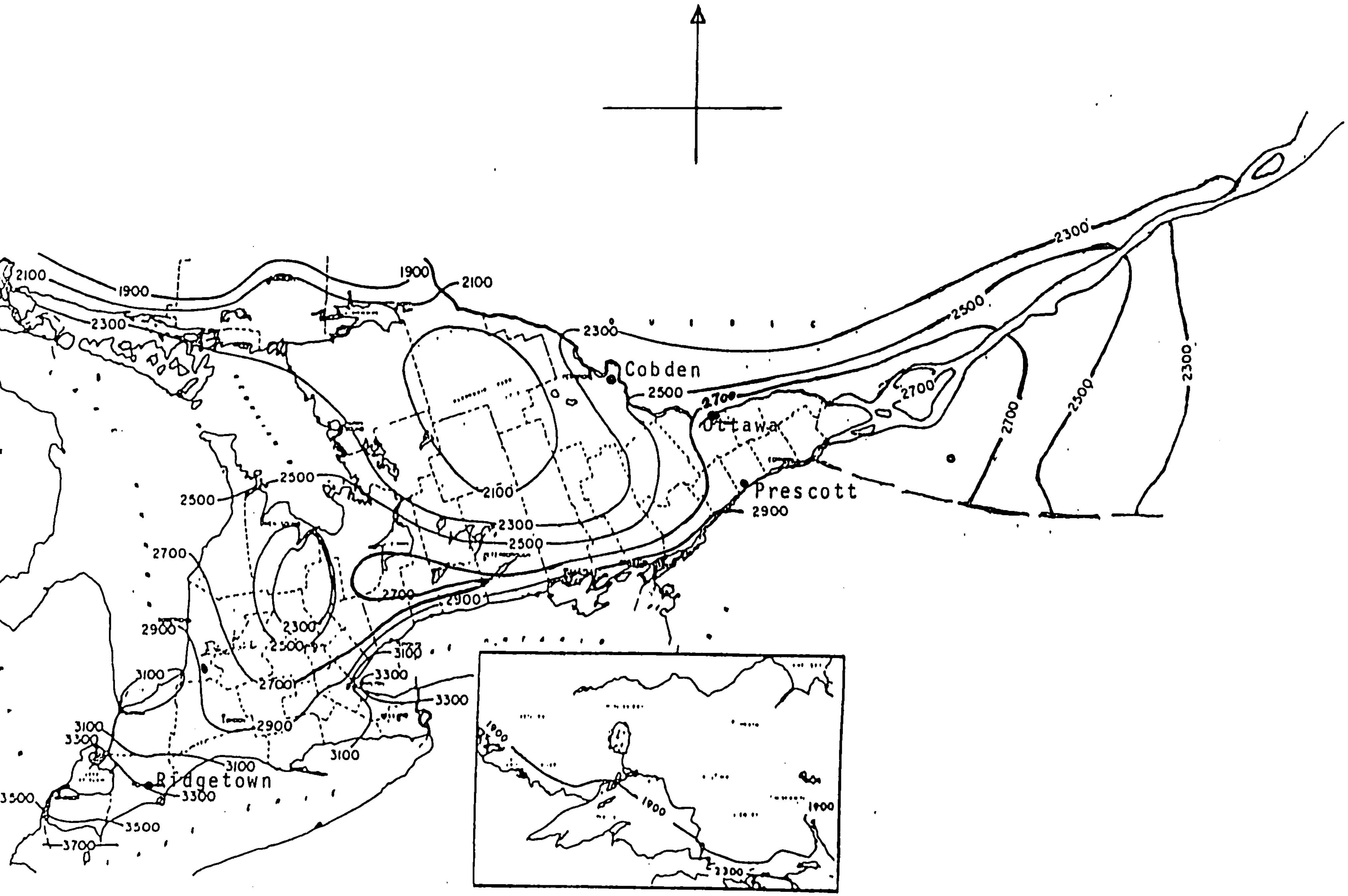
Maize, *Zea mays* L., has changed drastically with modern plant breeding. This crop is an annual monoecious plant adapted to short day length (Bockholt 1979) and requiring daytime temperatures above 20°C and night temperatures above 14°C for optimum yield (Hartman *et al.* 1981). There are six types of corn plants: popcorn, flint, flour, dent, sweet and waxy corn (Heiser 1990). Advances in maize breeding have resulted in yield improvements of ca. 600% since the late 1860's in United States (Hallauer *et al.* 1988) and a reduction of the growing season from 100 days to 60 days. As a result, maize can now be cultivated as a grain crop in Alberta, Québec, Ontario and the Atlantic provinces.

United States is the principal producer of maize in the world and ninety percent of its production is grain corn (Chiang 1978, Janik 1981; Hallauer *et al.* 1988). Maize is primarily grown in the central corn belt comprising Iowa, Illinois, Minnesota, Indiana, Nebraska, South Dakota and Ohio. The Southern states (Georgia, Carolina, Virginia) are improving maize resistance to rust and other diseases while the Northern states (Pennsylvania, New York) are developing shorter-season inbreds with some degree of cold tolerance (Aldrich *et al.* 1986).

In Canada, maize is grown on 1.1 million hectares, producing more than 16.4 million metric tons with a farm value of roughly 500 millions dollars in 1991 and 1992 (Statistic Canada 1993). Maize is cultivated in Ontario (65%), Québec (30%), Alberta, Manitoba, and Prince Edward Island (Anon 1992). The Canadian objective is maize adaptation to northern latitude, earliness (short season), and pest resistance (corn borer, rootworms, other insects and *Fusarium* fungi). The province of Ontario is divided into 8 corn heat unit (CHU) zones from 2350 to 3400 CHU (Figure 1.1 from OCPA). The growing season in eastern Ontario is 15 days shorter and roughly 700 CHU less than the southern region. Thus inbreds developed at the Eastern Cereal and Oilseed Research Centre at Ottawa are suitable for Ontario (2350-2750 CHU), Québec (2500-2700 CHU), Alberta (2500 CHU), Manitoba (2400 CHU) and Prince Edward Island (2400 CHU).

European corn borer, *Ostrinia nubilalis* Hübner, is the most important insect pest of maize in North America (Burkhardt 1978; Dicke and Guthrie 1988) with loss of 3-10% per year, i.e., $12-50M. Its life cycle is intimately related to maize developmental stages (Guennelon and Audemard 1960). Corn borer is a polyphagous insect and produces one or two generations per year according to geographical location (Beck 1987, Jarvis *et al.* 1983, Hudon and Leroux 1986).

Figure 1.1. Heat units available for maize production in Ontario and Québec.
(Each value represent a specific CHU isoline)

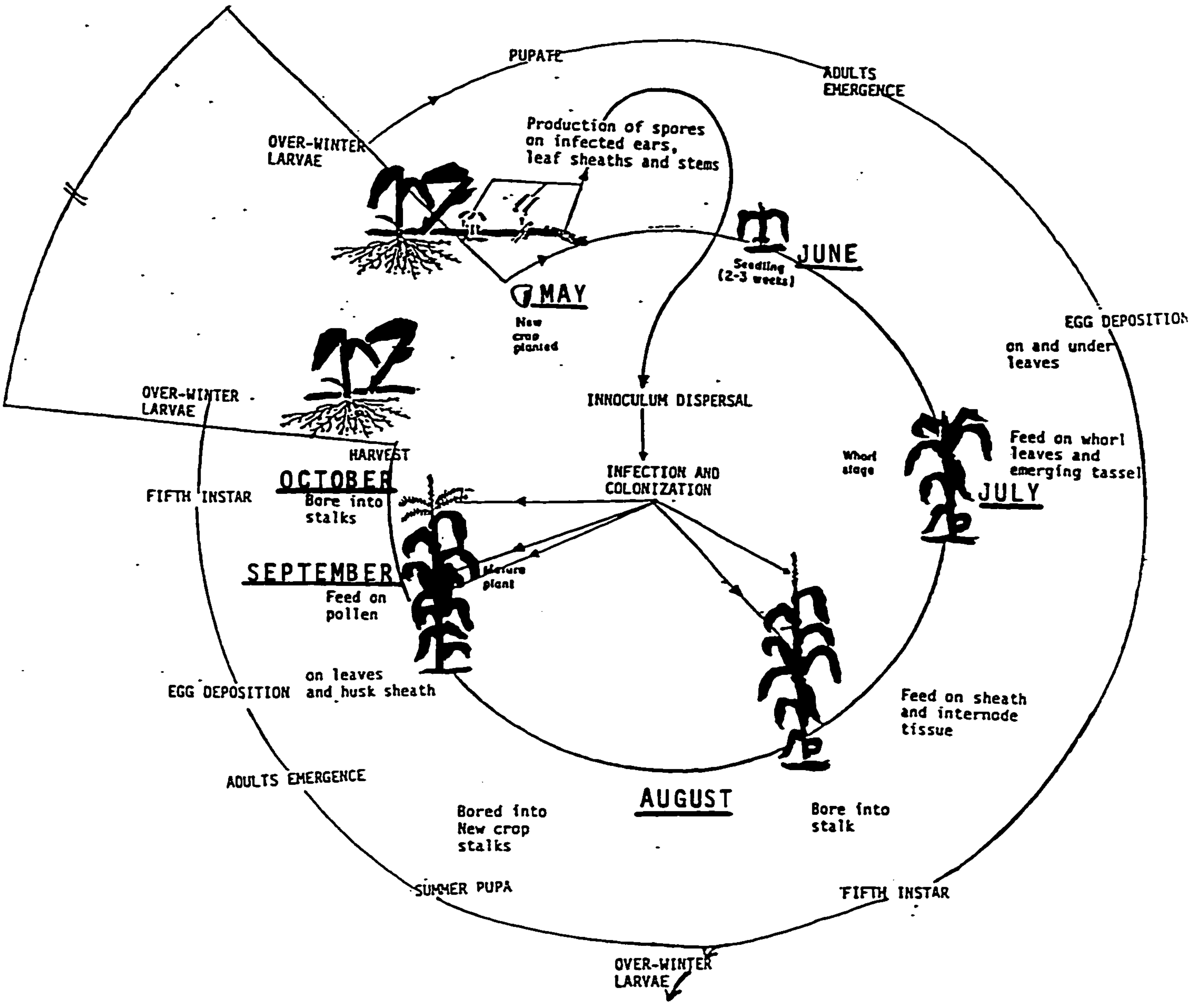

Cobden
Ottawa
Prescott
Ridgetown
1900
2100
2300
2500
2700
2900
3100
3300
3500
3700

3a

The borer overwinters as a mature larva in the stubble (Figure 1.2), stalk or other corn refuses. The following spring it spin a flimsy cocoon, pupate and finally transform into a moth before chewing its way out. The first brood of adult females deposits eggs on the tallest genotypes (Hudon and Leroux 1986) i.e., when corn has reached the 10th leaf of the whorl stage of development (Dicke and Guthrie 1988, Hudon and LeRoux 1986). There are five larval instars. Upon hatching, the neonate larva disperses to feed on the foliar parenchyma of young leaves. The second instar chews and enters the whorl to feed on yellow leaf tissue, protected from natural ennemies and desiccation (Hudon and LeRoux 1986). The third instar feeds on the leaf sheath, collar tissue and on the male inflorescence (tassel) within the whorl and are transported passively upward as the plant grows. At the fully elongated plant stage, the larva feeds on the tassel floret, pollen, bores into the tassel shaft, drills into the leaf mid-rib vein causing leaf breakage as it migrates downward and bores into the stalk eating pith tissue above the ear node. The fourth and fifth instars feed in the mid-rib vein of the leaves, collar sheath, ear grain, rachis, shank, and stalk-pith, making galleries. When corn reaches the anthesis stage (pollen shedding), eggs of the second brood of the June population are deposited. The first to fourth instar larvae feed on pollen, tissues of the husk, silk and ear shoots. The larvae attains the fifth instar stage before winter settles and overwinter in the stubble, stalks and other maize refuse.

The corn borer may aid in the development of fungal rot by providing a port of entry for the fungi; distributing the fungi inside the plant as the larvae move; the frass within larval tunnels may serve as an organic substrate, favouring the multiplication of mycelium; and through pith injury caused by tunnelling (i.e., degradation of adjoining tissues), the larva initiates cell senescence (plant stress), pith breakdown and fungal rot dissemination within the stalk (Christensen and Schneider 1950; Chiang and Wilcoxson 1961).

Figure 1.2 **Seasonal development of the European corn borer, *Fusarium*, maize plant, and the two-way association between corn borer & maize and *Fusarium* & maize in Eastern Ontario.**


PUPATE
ADULTS EMERGENCE
OVER-WINTER LARVAE
Production of spores on infected ears, leaf sheaths and stems
JUNE
Seedling (2-3 weeks)
MAY
New crop planted
EGG DEPOSITION
on and under leaves
INNOCULUM DISPERSAL
OVER-WINTER LARVAE
HARVEST
INFECTION AND COLONIZATION
Whorl stage
Feed on whorl leaves and emerging tassel
JULY
OCTOBER
Bore into stalks
FIFTH INSTAR
SEPTEMBER
Mature plant
Feed on pollen
on leaves and husk sheath
EGG DEPOSITION
Feed on sheath and internode tissue
ADULTS EMERGENCE
AUGUST
Bored into New crop stalks
Bore into stalk
SUMMER PUPA
FIFTH INSTAR
OVER-WINTER LARVAE

***Fusarium* stalk rot** is the most severe and common disease of maize (McGee 1988). Stalk rot involves a complex process where bacteria and fungi participate in tissue degradation. Stalk rot cause premature plant death and contribute to stalk lodging (Smith and White 1988). The diseased plant usually collapses at the first or second internode above the ground and falls over (Whitney and Mortimore 1956); this makes harvesting more difficult, and time-consuming. Also, yield and grain quality are reduced. Despite annual variation in degree of infection, stalk rot persists and is ubiquitous. Even within the same field and same genotype, the distribution of the fungus is localized in a patchy distribution. The plant-fungus relationship can be described as antagonistic and ultimately results in stalk breakage.

Stalk rot is the premature degradation of internal vascular tissues in the stalk and is related to the onset of senescence. It usually produces no visible symptoms until the plant has reached full physiological maturity. The occurrence of stalk rot is favoured by dry and warm weather (>30^{0}C)(Cosmin *et al.* 1987) early in the growing season followed by extended periods of rainfall shortly after silking. Several factors influence stalk rot occurrence: moisture availability, grain fill and kernel number, cultural practices, plant densities, and insect and bird damage (McGee 1988).

Perithecia on infected maize stalks mature under warm and wet conditions, and exude ascospores which are carried by air currents to ears or stalks where they are deposited (Figure 1.2). They initially grow on pollen that is trapped in the leaf collar sheaths, then enter the weak tissues where they germinate. During warm and moist summer months, a pinkish-white mycelium producing conidia grows within damaged plant parts. The fungus overwinters on maize debris, such as stubble, ears, and rachis from which ascospores and conidia are released the following season.

The first disease symptoms are dull leaves, premature plant senescence, fallen ears, and stalk discoloration. In the latter case, the pith at the base of the plant becomes rotten and detached leaving only the vascular system. Then, the stem structure changes to become a weak tube susceptible to weather. On the external stem surface some round and blackish perithecia are formed. These detach easily for dispersion.

The amount of stalk breakage in corn production is at times severe because of wind, frost damage, insects or fungal diseases. Climatological conditions during the growing season affect plant physiological development and grain moisture at harvest. As grain harvest approaches, the plant structure changes significantly (Foley 1983), therefore the maintenance of a certain degree of stalk physiological vigour during the post-maturity period ensures protection against stalk rot infection (Wall and Mortimore 1965). This is the period when borer and stalk rot damage is most acute.

Genetic resistance in maize: Genetic tolerance studies require identification of the major pest species, strain population, life cycle, population dynamics and knowledge of pests behaviours. Resistance to the European corn borer in June (first-generation of the bivoltine strain) and in July (univoltine strain) is best described as leaf-feeding resistance. Resistance to the August population (second-generation of the bivoltine strain, and non-diapausing univoltine borer) is more collar and ear sheath-feeding resistance (Guthrie *et al.* 1971). In eastern Ontario, current genotype selection has been achieved by infestion with univoltine borer. Since 1988, the bivoltine incidence has doubled and it may very well be that selection will soon be required for genotypes that are resistant also during pollen-shedding in August. Presently, only a few genotypes tolerate all borer populations. This is because genes controlling resistance to each of the two generations are mostly independent (Jennings *et al.* 1974). As new lines are being developped (5-10 years), new gene are introduced which induce new defence mechanisms. However, in a monoculture such as maize, four main components (genetic, cultural, soil and climatological) interact giving rise to more than one hundred of interactions such as crop by pest, genotype by pest, crop by land preparation, pest control, light, soil-type, fertility, rain distribution, etc., etc. (Francis 1986). Concurrently, pest and pathogen also develop new ways of overcoming host-plant defences through developmental time (Pirozynski and Hawksworth 1988). Consequently, tolerance of genotypes to corn borer does not necessarily imply tolerance to stalk rot (Klenke *et al.* 1987).

Plant breeding: Eastern Ontario is a formerly non-traditional region for grain corn production due to its short and cool season. Plant breeding programs began at the Ottawa Research Station in 1927 and for many years concentrated on adaptation, early maturity and yield improvement. Over the years, many progress have been made in reducing maturity, modifying plant architecture, and achieving high yields. However, stalk strength and resistance to breakage still require improvement (OCPA, Annual Hybrid Corn Performance Trials Reports 1937-1989). In the last decade, sources of stalk strength and corn borer tolerance have been incorporated into these adapted hybrids (Annual Reports 1980-1988, P.R.C. Research Branch, Agric. Canada). A much better understanding of the European corn borer, *Fusarium*, and maize complex may allow further progress to be made.

Phytochemistry of resistance

European corn borer: The biochemical nature of leaf feeding resistance to the first generation of borer was initially attributed to the hydroxamic acid 2,4-dihydroxy-7-methoxy-1,4-benzoxazinone-3-one (DIMBOA), or its degradation product 6-methoxy-benzoxazolinone (MBOA)(Klun and Robinson 1969). Secondary metabolites such as DIMBOA can reduce insect fitness resulting in slow developmental rate, reduced pupal and adult size, lower fecundity and viability, increased mortality, behavioural changes such as antifeedancy, repellency and dispersal (Campos *et al.* 1989, Wright *et al.* 1982). Concentrations of DIMBOA are highest at the seedling stage and then decrease rapidly after the 10-leaf developmental stage (Bergvinson 1993) which coincides with the July population appearance. Guthrie *et al*. (1986), on the other hand, identified some genotypes with leaf feeding resistance and low concentrations of DIMBOA. This suggested that other factors may be involved in borer resistance, such as silica, lignin, neutral detergent fiber (Coors 1987) and secondary metabolites such as diferulic and truxinic acids (Bergvinson 1993).

***Fusarium*:** All microorganisms and plants produce natural products that are not essential for the primary metabolism of the organisms. The presence of MBOA in maize was found to be inhibitory to the growth of *Fusarium moniliforme* and *Gibberella zeae* in Ontario (Whithney and Mortimore 1957). Conversely, *Fusarium* fungi produce a multiplicity of toxins (Bu Lock 1980; Miller and Greenhalgh 1988) that are either acutely toxic to vertebrates or mutagenic (Wicklow 1988). Dowd (1989) demonstrated that a diet prepared with the toxin produced by *F. moniliforme* (fusaric acid) and maize compound (MBOA) and fed to corn borer larvae, reduced larval weight and increased mortality significantly. However, these mycotoxins tend to be produced when plants reach full maturity (Miller and Trenholm 1993).

Plant structure: Poor standability resulting from weakened stalks can be due to stalk-rind thickness, insect-tunnel damage, fungal stalk rot, weather and related cultural stress including cultural practices, plant densities, excessive fertilization, soil moisture and tillage (Bergstrom 1984, Foley 1987). The effect of increased cell wall lignification, in addition to reinforcing the plant, seems to have an antagonistic effect on the borer behaviour by reducing nutrient uptake, digestibility, and reduced general fitness. Therefore, the elasticity *per se* of the corn stalk is very important to ensure stalk standing. Increasing stalk diameter will not overcome all of the borer and rot problems related to stalk breakage. The corn borer makes galleries in the stalk, while early stages of stalk rot detach the parenchyma from the rind. In both instances, a hollow tube structure is created.

Reducing insect pressure by agronomic practices may be one of the methods of overcoming prolonged exposure to specialized pests. Moreover, identification of other mechanisms of resistance could also result in reduction of pest-pathogen fitness within the plant. Miller and Trenholm (1993) have shown that mycotoxins appear mainly when the plant is fully mature. At plant maturity, the corn borer has reached full maturity and prepared to overwinter (Hudon and Leroux 1986b). Consequently, tolerance of genotypes to corn borer does not necessarily imply tolerance to stalk rot (Klenke *et al.* 1987) because of different host-pests infestation/infection chronology. Swain (1979) cautioned that there is perhaps an overemphasis on resistance conferred by specialized toxins; and it is perhaps important that research focus on the interactions of toxigenic fungi with animals living in the same habitat.

This thesis attemps to characterize the tripartite association: European corn borer, *Fusarium*, and maize plant, relative to recent cultural, climatological and pests seasonal history changes in three maize ecotones of Eastern Ontario.

HYPOTHESIS AND OBJECTIVES

In a monoculture such as maize, four main components interact simultaneously, i.e., crop genetic, cultural practice, soil property and climate (Francis 1986). These same four components also interact with pest and pathogen biology to permit seasonal adjustment, behavioural and epidemiological changes, and the development of new ways of overcoming host-plant defences through developmental time (Pirozynski and Hawksworth 1988). Stalk breakage resulting from European corn borer and *Fusarium* are considered the most important limiting factor in further yield increase of modern maize cultivation. Concurrently, there is great difficulty in distinguishing whether the corn borer damage or *Fusarium* rot is the principal instigator of stalk breakage. Moreover, the natural stalk rot epidemiology is not well understood.

The individual two-way interaction of the corn borer with the maize plant, and of *Fusarium* with the maize plant are well studied; but the tripartite interaction among the fungus, maize, and insect is not as well documented. In order to improve and characterize breeding selection criteria, a study on maize and its important pest complex, the European corn borer and *Fusarium* stalk rot, was initiated in three maize ecotones of Eastern Ontario. Elite genetic lines from the world's northern temperate zone programs, were examined at three sites that represent a thermal gradient at the limit of maize cultivation in Ontario.

Central hypothesis

Maize and its important pest complex, including the European corn borer and *Fusarium* stalk rot are an interactive biological system in which the outcome of any of the two-way interactions may be influenced by the third component.

Research objectives

In order to further improve maize resistance to corn borer and *Fusarium* fungus, it is necessary to characterize this association. To test this hypothesis I set-up experiments with the following objectives:

1a. Determine new maize selection criteria for European corn borer resistance relative to recent cultural, climatological and pest seasonal history changes in three maize ecotones of Eastern Ontario.

b. Determine the seasonal history of the *Fusarium* fungi in each of these ecotones.

c. Determine the percentage of each *Fusarium* dispersion modes in relation to stalk rot infection and genotypes maturity.

2. Determine the rôle played by the European corn borer in *Fusarium* stalk rot occurrence.

3. Identify some leading indicators of European corn borer and *Fusarium* stalk rot resistance.

4. Develop a model for Eastern Ontario of the *Fusarium* stalk rot mode of infection.

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Chapter 2.

Adapting evaluation techniques for leaf and stalk damages by European corn borer, *Ostrinia nubilalis* (Hübner), in eastern Ontario.

INTRODUCTION

In Ontario, maize production (*Zea mays* L) had a farm value estimated at $534.6 millions in 1993 (OMAF 1993). The European corn borer, *Ostrinia nubilalis* (Hübner), is the principal insect pest (Dicke and Guthrie 1988) and its larval stage, the solely injurious stage. The larvae feed on the leaf, tassel, cobs and stalk pith tissues. The latter leads to significant stalk breakage and yield reduction (Godfrey *et al.* 1991, Hudon *et al.* 1989). In eastern Ontario, plant breakage varied between 0% and 58% during the 1960-1992 period (OCPA Annual Report 1961 to 1993) with an estimated annual yield loss of roughly 17%. Furthermore, stalk breakage extended the harvest, reduced the crop quality and increased fungal susceptibility.

European corn borer: This pest was first identified in North America in the eastern United States around 1914 (Vinal 1917) and was detected in Ontario in 1920 (Parks 1926). In 1926, the "European Corn Borer Journal" was published (14 numbers) and reported on the borer status, systematics, geographical distribution, biology, damage types, regulation, biological, cultural and mechanical repression. Concurrently, a monograph on the corn borer investigation was published (Caffrey and Worthley 1927). Many studies have addressed the corn borer with maize interaction. However, this insect has remained a serious pest and a limiting factor in further expansion of maize yield (Reid 1989). The adaptive potential of this insect can best be illustrated by its polyphagy, voltinism, behaviour and adjustment to cultural practices including monocropping, continuous maize and conservation tillage. All these changes have been introduced concurrently and their impacts are not fully understood nor documented.

Beginning in 1988, "Branch reports" from Agriculture Canada documented the seasonal pest status in eastern Ontario. These reports indicated the occurrence of two periods of adult activity with the main moth flight and oviposition event arising in mid July. The larval stage feeds on the epidermal leaf tissues, then inside the whorl on the growing tip and tassel bud. At the fully elongated plant stage, the larva chews the tassel floret, and drills the tassel shaft. As the larva begins migrating downward, it feeds inside the leaf-collar sheath, eats the ear grain, tunnels the mid-rib vein, rachis, shank and bores the stalk eating pith tissue. By mid-September the larva has descended to the lower 30 cm of stalk and is undisturbed by harvesting practices. The second generation accounts for 8.5% of the yearly population.

Maize: Information pertaining to genotype evaluation is published in the Inter-Regional Maize Inbred Evaluation handbook (Darrah 1985) and contains line characteristics and genotype susceptibility to insects and maize diseases. Since 1985, many new inbred lines have been released but limited information is available pertaining to insect resistance. Concurrently, in Québec and Ontario a shift in borer voltinism was observed (Hudon 1959, Hudon *et al.* 1991, McLeod 1976, McLeod *et al.* 1979, Wressel 1952), and concomitant with the proliferation of conservation tillage practices (minimum, no-till, ridge tillage and others), borer survival was improved.

In Ontario, stalk breakage has been attributed indiscriminantly to insects and fungal rot. Concurrently, the impact of the European corn borer on corn improvement and expansion seems directly related to the factors that govern maize development, current corn borer phenology and host-pest synchrony.

Classical selection for first generation resistance (leaf feeding) developed by Guthrie *et al.* (1960) for United States does not apply to Canada, therefore maize breeding improvement in Canada relies mainly on plant dissection at grain harvest. It was hypothesized that maize resistance to the corn borer was dependent on maize genotypic physiological development, the capacity of the corn borer to adapt rapidly to seasonal climatic changes (e.g., multivoltinism, behavioural adjustment), and host-pest synchrony. Consequently, new selection criteria were developed to improve and characterize the mechanism of resistance/tolerance to the corn borer.

MATERIAL AND METHODS

Site, cultivars and pest information: The study was initiated in 1991 in three growing zones of eastern Ontario. Cobden (2400 Corn Heat Unit) and Prescott (2850 CHU) zones are located 96 km north and 80 km south of Ottawa site (2750 CHU) respectively (Figure 1.1 in Chapter 1, Appendix 2.1). Each of these growing zones represent a particular ecotone. Experiments were conducted on sandy loam and field plots were prepared according to producer practice, i.e., conventional tillage in Cobden (fall plowing and spring discing), minimum tillage in Prescott (one or two discing in the spring), and a modified conventional practice in Ottawa [flailed (Ford lawnmower model 917) and plowed in the fall, followed by discing one time the following spring].

A split-plot experiment with four replicates surrounded by four rows of a commercial hybrid (Pickseed 4533) was used at all locations. Genotype-group constituted the main-plot unit (hybrid, inbred, and synthetic) and genotypes the sub-plot unit. Each genotype was randomized within genotype-group. Each main-plot measured 178m long by 10m deep with a 2m path between replicates. Each row (8m long) comprised 40 plants to give a plant density of 24,000 plants/acre.

Thirteen inbreds representing three maturity groups: early (60-68 days to silking), medium (69-80 days), and late (81+ days); six synthetics (65-90 days) and three commercial hybrids adapted to eastern Ontario (70-80 days) were used (Table 2.1). Tasselling and silking dates for each genotype were determined when 50% of the plants/row attained these physiological stages.

At Cobden and Prescott (CHU extremes), genotypes were naturally infested by the European corn borer whereas in Ottawa, where population was to low, genotypes were artificially infested with borer egg masses to produce a uniform infestation.

Table 2.1. Genotypes grown at Cobden, Ottawa, and Prescott.

			Study site (CHU)					
	Rating		Cobden (2400)		Ottawa (2750)		Prescott (2850)	
Inbreds	corn borer	*Fusarium*	1991	1992	1991	1992	1991	1992
early								
CG16	s	s	x	x	x	x	x	x
CK44	s	R	x	x	x	x	x	x
CO266	s	R	-	x	x	x	x	x
CM7	s	s	-	x	x	x	x	x
CO273	s	s	x	x	x	x	x	x
medium								
A619	R	s	x	x	x	x	x	x
MS72	s	s	x	x	x	x	x	x
FRH	unknown	unknown	-	x	x	x	x	x
late								
B73	s	R	x	x	x	x	x	x
B86	R	R	-	-	x	x	x	x
CI31A	R	R	-	-	x	x	x	x
DE811	R	R	-	-	x	x	x	x
OH43	R	R	-	-	x	x	x	x
Hybrid								
medium								
3925	s	s	x	x	x	x	x	x
4533	s	s	x	x	x	x	x	x
late								
435	R	R	x	x	x	x	x	x
Synthetic								
early								
PRC01	s	s	x	x	x	x	x	x
PRC02	s	s	x	x	x	x	x	x
medium								
PRC04	s	s	-	x	x	x	x	x
late								
PRC03	s	R	-	-	x	x	x	x
BS9C0	R	R	x	x	x	x	x	x
BS9C4	R	R	x	x	x	x	x	x

Note: s: susceptible; R: resistant; x: grown; -: not grown
Rating based on assessments given in Darrah (1985), OCPA (1991) and R.I. Hamilton (pers. comm.).

Artificial infestation: The original corn borer population came from infested stalk residue collected at Exeter (43°21′N, 81°29′W) and stored outside for winter at Ridgetown College of Agriculture, Ridgetown, Ontario. In the spring, stubble was moved into a controlled environment room (Pitblado, 1989) and insects reared according to the technique described by Guthrie (1989). Wax paper discs (1.3 cm diameter) with one egg mass (20-25 eggs) were shipped to Ottawa during the first, second and fourth week of July and incubated at 25°C, 80% RH, and 24h of light until the black head stage.

The first and last five plants of each row were not infested (border plants) and the inner 30 plants received four egg masses per plant (ca. 100 eggs) deposited in two lots of two egg masses in the plant whorl prior to stem elongation and tassel emergence (Guthrie *et al.* 1965; Gahukar 1975). Two additional egg mass discs were attached to the ear sheath (early-, and mid-maturity genotype) or placed in the whorl (late maturity) after the leaf-feeding assessment had been conducted during the fourth week of July, to mimic 2nd generation infestation.

Residue samples: Weekly from snow melt to mid-July, fifty randomly collected maize stubble-stalks (20-50 cm long with the root) were dissected from each site. Stubble samples provided spring phenology (overwintering success, pupa and adult emergence).

Crop sampling: From late-June to September, 40 plants (grower's commercial hybrid) were dissected weekly to determine seasonal history and behaviour. Voltinism was determined by the recovery of fresh new pupae and empty pupal cases from the actual crop.

Leaf feeding: To detect and monitor feeding activity in the vicinity of the plot, I developed a simple plant defoliation assessment of 300 randomly choosen plants. The rating was as followed: whole plant without leaf feeding received a score of zero; plant with less than 20% of total plant-leaf damage a score of 1; and plant with more than 20% a rating of 2. This assessment was conducted twice (at one week intervals) beginning the third week of July.

Genotype assessment was conducted during the last week of July using the 9-class rating scale of Guthrie *et al.* (1960) aided by a new 5-class plant-leaf damage visual appearance (Table 2.2, appendix 2.2).

Harvest: Silage (mid-September) and grain harvest (mid-October) were conducted manually. Each time, maize plants for each genotype were dissected longitudinally to evaluate corn borer damage.

At silage, seven plants per genotype and replicate were dissected. Then stalks (including the cob) were shredded using a leaf shredder. Plant material was weighed and then put in a Unitherm oven (49°C) for 5-10 days (until no more weight variation was observed) to determine percentage of moisture. At grain harvest, ears of 10 plants were hand picked, shelled, weighed and dried in a Unitherm oven to determine the genotype grain-moisture.

At both harvests, the location and length of each tunnel and the number of larvae per tunnel were recorded. Genotype and borer data were then examined to identify some genotype characteristics that relates to corn borer susceptibility indicators.

Statistical analyses were performed on raw data using SAS version 6.03 (SAS, 1988). Percentage were transformed using arcsin square root of the percentage (Little and Hills 1976) to satisfy the assumption of the general linear model. Comparision of the means within varieties and between treatments was only carried out if the treatment F-ratio was significantusing Student-Newman-Keul's (SNK) test.

Weather: Daily maximum-minimum temperature and precipitation were recorded at each site from April 1st to October 31st in 1991 and 1992. Monthly maximum/minimum average temperature and total rainfall were calculated (Appendix 2.3). The daily corn heat unit (CHU) was derived from maximum/minimum temperature following the method of Major *et al.* (1976). A genotype CHU ratio was calculated by dividing the seasonal CHU from planting to the first killing frost ($-2^{0}C$) for each of the locations by the genotype CHU rating given by seed companies(Appendix 2.4). The CHU and CHU-ratio were

Table 2.2. Modified leaf rating scale using Guthrie *et al.* (1960) scale aided with a plant-leaf damage index developed for this study (see visual description in Appendix 2.2).

Plant appearance	Guthrie et al. (1960) Leaf rating
1.0: no damage	
1.5: less than 10% of the leaves damage	1.0: no or slight damage
	2.0: shot-hole lesion/ injury on few leaves
2.0: less than 33% of the leaves damage	3.0: shot-hole injury on several leaves
	4.0: shot-hole/elongated injury on several leaves
3.0: less than 66% of the leaves damage	4.0: shot-hole/elongated injury on several leaves
	5.0: elongated lesions on several leaves
4.0: over 66% of the leaves damage	5.0: elongated lesions on several leaves
	6.0: large elongated lesions on several leaves
	7.0: long lesions on half of the leaves
	8.0: long lesions on two-third of the leaves
	9.0: long lesions on all the leaves

then correlated to the number of days to pollen shedding,silking event, silage, grain moisture and corn borer parameters to determine host/pest synchrony.

RESULTS AND DISCUSSION

Weather and plant development: Accumulated CHU increased on the Cobden-Prescott (north to south) gradient in 1991 and 1992 (Figure 2.1). Plant stages and grain moisture were significantly correlated with corn heat unit ratio for each location and years (Table 2.3). Correlation coefficient between silage moisture and CHU ratio was statistically significant ($p<0.05$) for Cobden and Prescott in 1992 only, and Ottawa (1991 & 1992). The ratio index was not correlated for silage harvest at Prescott in 1991 because harvest was conducted in late-August, when excessive variation between genotype moistures content were recorded.

Overall, the two growing seasons are better described as hot and dry (1991) and wet and cool (1992)(Bootsma and Brown 1993). In Cobden and Ottawa, genotypes were planted in the 3rd week of May whereas at Prescott, seeding occurred in the 1st week of May. In 1991, the drought conditions did not affect as much genotype development at Cobden because of the lower maximum temperature, reduced maximum/minimum variation, and shorter drought exposure (northern location)(Appendix 2.3). The drought conditions in Ottawa and Prescott favoured CHU accumulation, diminished grain moisture at harvest, caused poor synchrony between shedding pollen and silking (e.g., B86), reduced pollen viability and yield. In 1992, the poor growing conditions between May and August (shortfall of roughly 100 CHU/month) retarded substantially plant development such as germination, pollen shedding, silking and maturity regardless of the location. The September frosts blocked abruptly ear filling (i.e., carbohydrate translocation) prior to the onset of the black layer stage. This increased plant breakage because of the stalk softness resulting from the degeneration of cell-wall structure (Aldrich *et al.* 1986). At grain harvest in October, genotype ranged between silking and dough stage of plant development depending on locations and genotypes maturity.

Figure 2.1. **Accumulated corn heat units in Cobden, Ottawa and Prescott in 1991, 1992 and the 10 years average (1981-1990).**

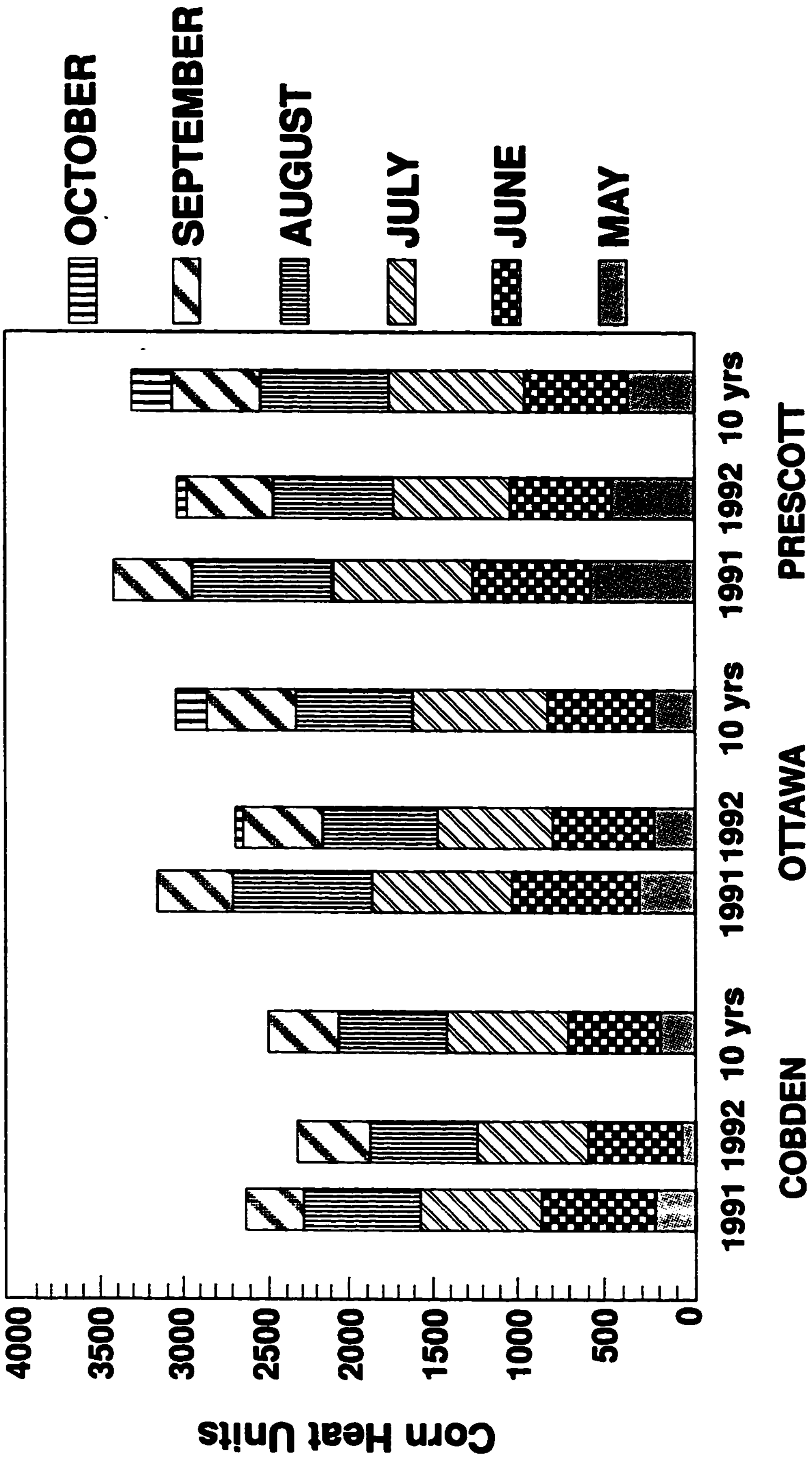

Corn Heat Units
4000
3500
3000
2500
2000
1500
1000
500
0
1991
1992
10 yrs
COBDEN
1991
1992
10 yrs
OTTAWA
1991
1992
10 yrs
PRESCOTT
OCTOBER
SEPTEMBER
AUGUST
JULY
JUNE
MAY

Table 2.3 Simple linear correlation for each location between two plant development stage, corn moisture parameters and the corn heat unit ratios in 1991 and 1992.
(N_{Cobden}= 13 genotypes, $N_{Prescott \& Ottawa}$= 22 genotypes)

		Days to 50%		Moisture at	
COBDEN		TASSEL	SILK	SILAGE	GRAIN
CHU ratio	1991	-0.94**	-0.94**	--	-0.86**
	1992	-0.91**	-0.89**	-0.56**	-0.84**
PRESCOTT					
CHU ratio	1991	-0.65**	-0.59**	-0.01	-0.43*
	1992	-0.66**	-0.76**	-0.66**	-0.67**
OTTAWA					
CHU ratio	1991	-0.81**	-0.81**	-0.57**	-0.85**
	1992	-0.41**	-0.88**	-0.66**	-0.72**

Data for each genotype are found in Appendix 2.4.
SILAGE : silage moisture (whole plants cut at 30 cm)
GRAIN : grain moisture
CHU ratio: Seasonal CHU divided by genotype CHU rating
* : Significant at the 5% level
** : Significant at the 1% level
-- : silage moisture was not determined in 1991

EUROPEAN CORN BORER: In 1991, there were three adult flights: one in the first half of June, the main in late June-early July and a third one in August. Oviposition occurred in late June, the first week of July and during August, respectively. For the first two populations, eggs were laid on the tallest genotypes. Neonate and second instar larvae chewed the leaf epidermal surface and then bore through the rolled leaf blade to feed on the yellow leaf tissue and the growing tip. Second and third instars fed on the tassel bud (yellow tissue not yet exposed to sun) during mid- to late-whorl plant developmental stage, then on the tassel floret, pollen, and into the tassel shaft when plants were at the fully elongated stage. As the third instar larvae migrated downward, then fed in the leaf collar sheath, drilled the mid-rib vein and bored into the stalk eating pith tissue (above the ear node). Fourth and fifth instars fed in the mid-rib vein of the leaves, inside the leaf collar sheath, and stalk-pith as they continued their downward migration (June population) whereas the latter fed upon ear grain, rachis and ear shank. The 1st population (June) gave rise to the August generation. Hot weather conditions in July accelerated larval development of the 2nd population and may have induced another generation in August if larval development was completed while daylength was longer than 14 hours. Otherwise, they prepared to overwinter. The third corn borer flight (August) oviposited on the ear sheaths and secondary tillers so the larvae could easily feed on tender husk tissue, grains, rachis, leaf collar sheath, and tunnel the stalk below the ear node as they continued their downward migration.

In 1992, one main flight occurred in July at all three sites. The June and August populations were observed only at Ottawa and Prescott and were small. Pupae of the August population were recovered only on weeds such as pigweed (*Amaranthus retroflexus* L.) and wild carrot (*Daucus carota* L.) suggesting that corn borer larvae had moved into these alternative hosts to pupate.

In both years, the fourth and fifth instar larvae migrated toward the base of the plant regardless of the plant developmental stage (mid whorl: June population; late whorl: July; grain filling: August). All the larvae aggregated in the first 60 cm of stalk from the soil surface.

Uninjured plants (damage-free): The highest incidence of uninjured plants occurred at Cobden (coldest location with normally one generation in July) and in late maturing genotypes (Table 2.4). The comparison of the percentage of genotype damage-free incidence between locations and years indicated some statistical difference between Cobden and Ottawa/Prescott locations (Table 2.5). This difference can be explained by the cooler temperature and smaller August population that resulted at Cobden.

Generally, the maize-pest synchrony determined the genotype damage-free incidence. The percentage of damage-free plants correlated positively with the number of days to attain silk stage (Figures 2.2 & 2.3). However, weather conditions modified plant development and pest seasonal history (including voltinism, oviposition, establishment and behaviour) such as in Cobden 1992. In Ottawa and Prescott, the weather impact was reduced because of borer voltinism. Moreover, in eastern Ontario, all genotypes grown had attained 10, 12 or 14 leaves stages, i.e., late, medium or early maturity respectively in early July. Coincidentally, females prefer to lay in the ear zone of the most advanced and tallest genotype (Hudon *et al.* 1985). It is possible that late genotypes escaped the early-July infestation because they were not acceptable as a food source, are shorter than adapted regional lines (non apparent), or there was presence of deterrent plant phytochemical (due to their delayed vegetative stage). Females of the August population oviposited on the later genotypes which are at the silking developmental stage or on secondary tiller. Generally, at that time, leaves and ear sheathes of the short season genotypes are too hard to permit neonate establishment.

Table 2.4 Mean percentage (± s.e.) of damage-free plants observed for each genotype at Cobden, Prescott and Ottawa at grain harvest in 1991 and 1992. (N=40 plants per genotype)

	Natural population				Artificial	
Maize	1991		1992		1991	1992
Genotype	Cobden	Prescott	Cobden	Prescott	Ottawa	Ottawa
Inbred						
A619	57.6 ±7.5	25.0 ±11.9	70.0 ±12.9	17.5 ±2.5	22.8 ±7.5	15.0 ±5.0
B73	49.1 ±7.1	7.5 ±4.8	40.0 ±18.3	4.4 ±2.5	4.2 ±2.6	5.0 ±2.7
B86	-	52.5 ±11.1	75.0 ±9.6	17.8 ±2.5	65.6 ±11.5	35.0 ±10.3
CG16	81.7 ±4.1	40.0 ±6.4	75.0 ±15.0	25.0 ±2.5	8.8 ±2.3	0.0 0
CK44	64.2 ±5.3	25.0 ±9.5	95.0 ±5.0	30.0 ±12.9	3.9 ±2.6	0.0 0
CI31A	-	37.5 ±9.8	-	25.0 ±4.8	24.6 ±9.3	60.0 ±18.9
CO266	62.2 ±5.2	14.5 ±1.9	80.0 ±11.6	13.3 ±5.0	5.5 ±2.7	0.0 0
CM7	39.7 ±9.2	7.5 ±2.1	75.0 ±10.0	22.5 ±4.8	5.1 ±2.7	15.0 ±5.0
DE811	-	47.5 ±11.8	-	52.5 ±12.9	48.1 ±8.9	35.0 ±16.3
MS72	39.3 ±4.8	12.5 ±7.5	75.0 ±12.6	5.0 ±2.8	12.7 ±4.1	15.0 ±4.1
OH43	-	17.5 ±5.8	80.0 ±11.6	10.0 ±5.8	25.0 ±7.3	25.0 ±12.0
CO273	64.3 ±7.7	12.5 ±4.8	75.0 ±9.6	12.5 ±2.1	5.1 ±1.5	5.0 ±1.5
FRH	31.1 ±8.0	7.5 ±1.9	65.0 ±5.0	8.9 ±2.5	10.0 ±4.6	5.0 ±1.5

Table 2.4 (cont'd).

Maize Genotype	Natural population				Artificial	
	1991		1992		1991	1992
	Cobden	Prescott	Cobden	Prescott	Ottawa	Ottawa
Hybrid						
3925	29.4 ±4.8	15.0 ±4.9	20.0 ±2.0	10.0 ±5.0	22.5 ±8.2	28.0 ±11.1
4533	28.6 ±7.1	20.0 ±4.1	35.0 ±9.6	7.5 ±3.5	16.3 ±6.4	12.0 ±2.5
435	39.0 ±5.5	35.0 ±8.7	55.0 ±5.0	32.5 ±5.0	22.5 ±9.4	20.0 ±7.0
Synthetic						
SFP1	36.3 ±5.2	7.5 ±0.7	50.0 ±12.9	8.9 ±5.0	14.3 ±4.8	4.0 ±0.8
PRC02	30.6 ±4.2	10.0 ±2.7	50.0 ±5.8	10.0 ±5.0	20.5 ±6.1	12.0 ±2.5
PRC03	-	20.0 ±4.1	-	22.5 ±4.8	32.5 ±10.3	4.0 ±0.8
PRC04	-	7.5 ±4.1	65.0 ±9.6	22.5 ±4.8	26.3 ±5.0	32.0 ±10.6
BS9C0	60.0 ±5.7	27.5 ±7.5	55.0 ±9.6	32.5 ±5.0	36.3 ±6.5	28.0 ±2.5
BS9C5	-	53.9 ±10.8	80.0 ±9.6	51.2 ±6.4	52.5 ±5.0	52.0 ±14.5

Table 2.5. Mean comparison test for pool-genotypes of the percentage of damage-free incidence between locations in 1991 and 1992.

	Years	
Locations	1991 (%)	1992 (%)
Cobden	48.7^{a} (N=15 genotypes)	64.0^{a} (N=19 genotypes)
Ottawa	22.1^{b} (N=22 genotypes)	19.4^{b} (N=22 genotypes)
Prescott	21.4^{b} (N=22 genotypes)	20.1^{b} (N=22 genotypes)
	F=6.66 $p<0.05$	F=11.51 $p<0.05$

Same letter within a column were not significantly different using SNK test, $P<0.05$

Figure 2.2 Correlation of the mean percent damage-free incidence against the number of days to silking of 22 genotypes in Ottawa in 1991 and 1992 (each point represent a different genotype).

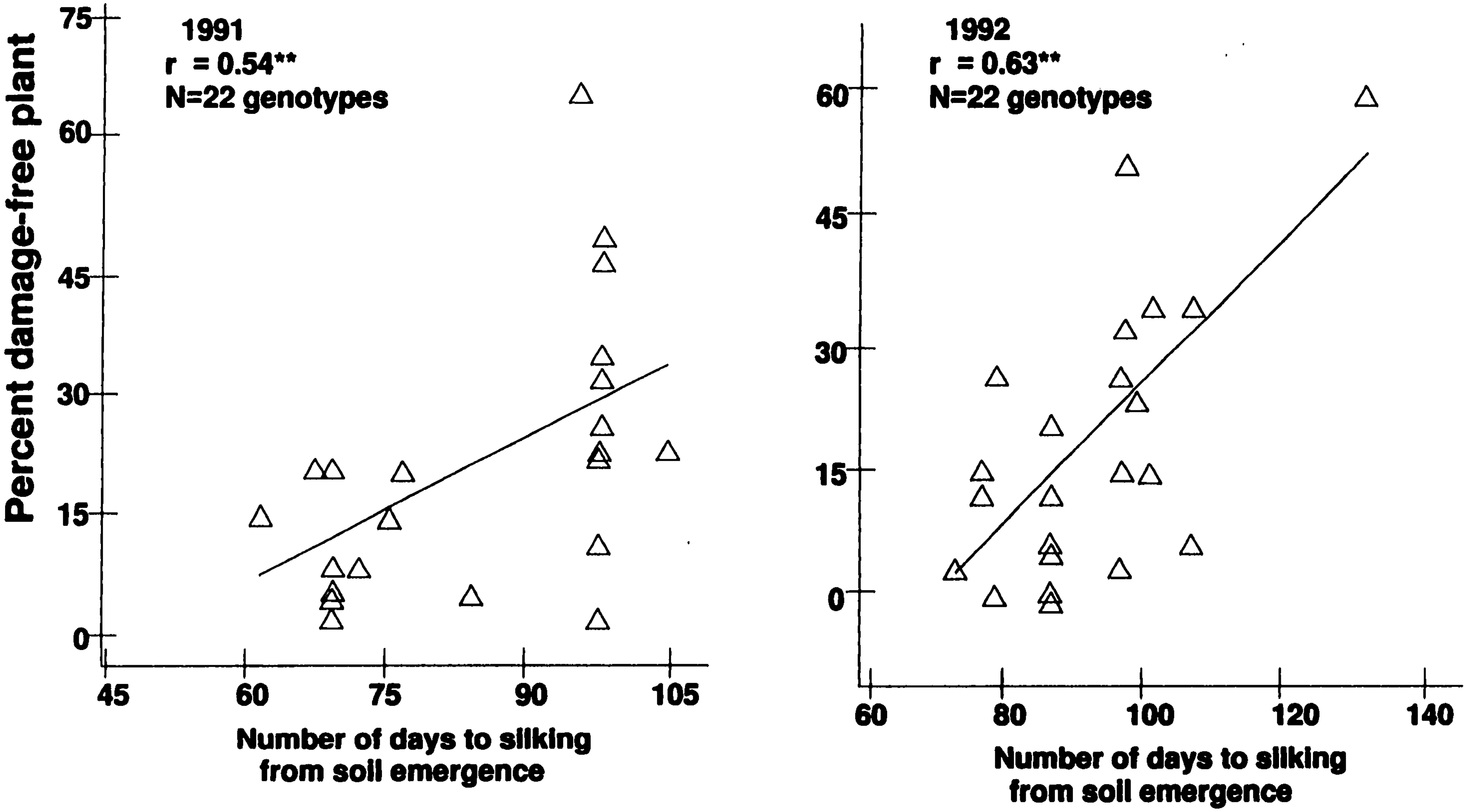
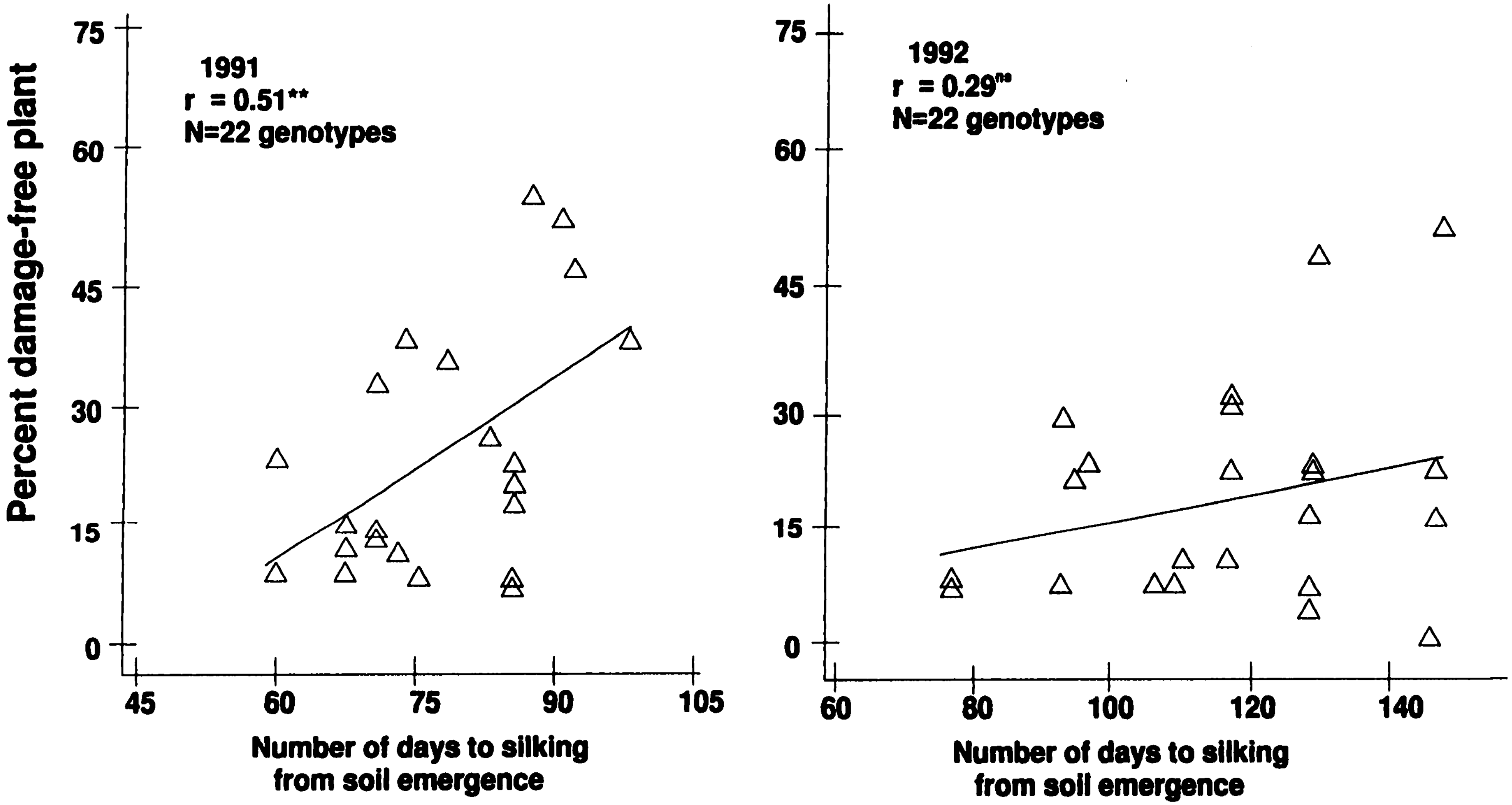

Percent damage-free plant
1991
r = 0.54**
N=22 genotypes
75
60
45
30
15
0
45
60
75
90
105
Number of days to silking from soil emergence
1992
r = 0.63**
N=22 genotypes
60
45
30
15
0
60
80
100
120
140
Number of days to silking from soil emergence

Figure 2.3 Correlation of the mean percent damage-free incidence against the number of days to silking of 22 genotypes in Prescott in 1991 and 1992 (each point represent a different genotype).


Percent damage-free plant
75
60
45
30
15
0
1991
r = 0.51**
N=22 genotypes
45
60
75
90
105
Number of days to silking from soil emergence
75
60
45
30
15
0
1992
r = 0.29ns
N=22 genotypes
60
80
100
120
140
Number of days to silking from soil emergence

Borer pressure: Dissection of farmer's hybrids in the fall of 1990 revealed that Prescott had the highest borer infestation (Table 2.6) due likely to borer voltinism and cultural practice. In 1991, the corn borer population diminished despite an increase of voltinism. This voltinism permitted the borer larvae to develop on various plant stages. Larval population decreased further in Cobden in 1992 due to the abnormally cool and wet conditions, while at Ottawa and Prescott, larval recovery was improved.

Corn borers are dynamic organisms in constant evolution. They adapt rapidly to crop development & improvement, climatic and cultural changes. **In 1991**, the first pupa was recovered May 2 and each month thereafter until September in Prescott giving rise to three to four adult flights. In Cobden, moths were captured in July and a partial 2nd flight in August was observed. The population size was small because of high egg and larval mortality (desiccation) and depletion of the food source (rapid drydown of the leaves, tassel and cobs). Larvae that did establish developed quickly. **In 1992**, the excessive rainfall and cooler temperature affected plant and pest development, host-pest synchrony, caused premature death of female moths (reduced oviposition), poor neonate establishment (drowning) and suppressed multivoltinism.

Leaf feeding: A plant-leaf damage index was used to aid in determining Guthrie *et al*. (1960) leaf rating assessment (Figure 2.4). This index is based on quantitative characters rather than qualitative and produced a uniform rating among appraisers.

Plant defoliation: A simplified defoliation index (0: no damage, 2: more than 20% of plant-leaf damage) was used to set the time to conduct genotype leaf feeding assessment.

Field surveys indicated that more than 60% of the growers' plants had no leaf damage in 1991 and 1992 (Table 2.7). This is not unexpected since egg-mass recovery in these maize fields attained 2-6 egg mass per 200 random plants examined in both years suggesting that females may have laid on other vegetations (weeds) or adjacent crops.

Table 2.6 **Mean number of corn borer larva for pool genotypes, at grain harvest in the first 30 cm of stalk, at Cobden and Prescott (natural population) and Ottawa (artificial infestation) between 1990 and 1992. (in parenthesis are the number of plants dissected)**

	Cobden	**Prescott**	**Ottawa**	**F value**
1990	0.63^{c} ±0.06 (1000)	2.01^{a} ±0.26 (1621)	1.20^{b} ±0.31 (1238)	5.32^{**}
1991	0.37^{b} ±0.07 (600)	0.91^{a} ±0.25 (880)	0.30^{b} ±0.09 (880)	17.79^{**}
1992	0.16^{b} ±0.08 (760)	1.32^{a} ±0.17 (880)	0.51^{ab} ±0.17 (880)	39.74^{**}

** $p<0.01$

Means within a year do not differ significantly if followed by the same letter using SNK test, $P<0.05$.

Figure 2.4 **Histogram representing the frequency of the Guthrie *et al.* (1960) leaf rating. The solid line represent the 4 index of plant-leaf damage.**

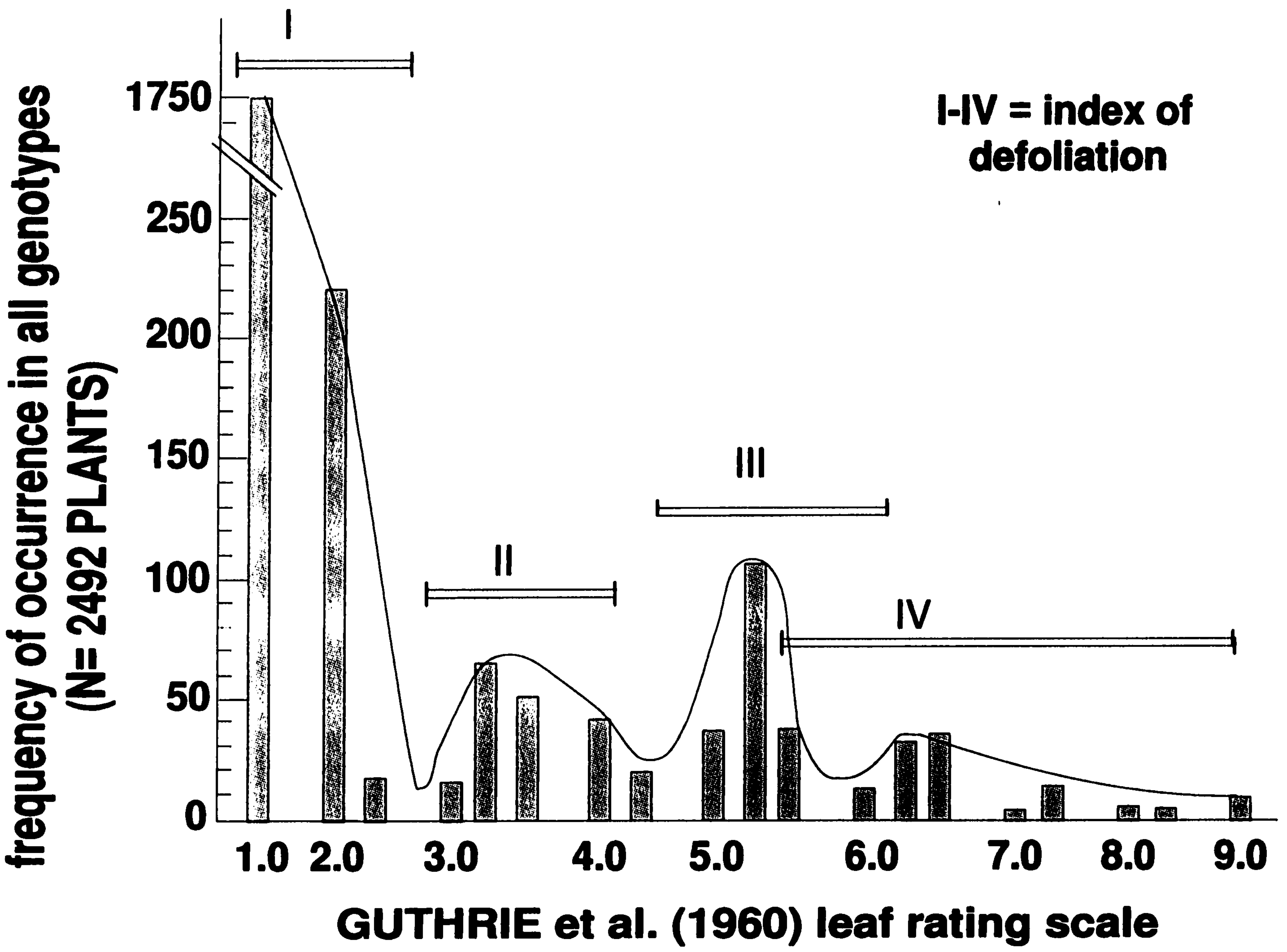

I-IV = index of defoliation
I
II
III
IV
frequency of occurrence in all genotypes (N= 2492 PLANTS)
1750
250
200
150
100
50
0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
GUTHRIE et al. (1960) leaf rating scale

Table 2.7 Result of the plant-leaf feeding survey conducted in farmers' commercial hybrid surrounding the experimental plot at each location in 1991 and 1992.

Plant-leaf	Cobden		Prescott		Ottawa	
rating	1991	1992	1991	1992	1991	1992
0%	51.8*	64.2	57.9	71.7	67.5	70.1
<20%	24.5	32.8	22.3	20.0	30.8	25.7
>20%	23.6	3.0	9.8	8.3	1.7	4.2

N=600 plants randomly evaluated per location and year)

* percentage

The greater leaf damage in 1991 at Cobden may be attributed to the reduced drought stress (northern site) and the extended plant vegetative growth (taller plants with longer internode; Dyers pers. comm.). In 1992, the damp weather at oviposition and during larval establishment in Cobden and Prescott resulted in reduced leaf damage.

Leaf rating: Genotype leaf rating varied with the growing season (Appendix 2.5). The overall leaf feeding did not differ between locations in 1991 (Table 2.8) despite the repetitive artificial infestation at Ottawa, but where statistically different in 1992. Ottawa recorded a higher rating in 1992, perhaps because of the repetitive and more successful infestation (egg mass deposition vs optimum establishment temperature). Within each location, the yearly climatic condition were the common factor that incfuenced the larval leaf feeding activity (Ottawa $F=169.5^{**}$; Prescott $F=4.11^{*}$).

Simple linear correlation analyses between corn borer and genotype parameters were conducted to measure the effect of corn borer on the genotypes susceptibility. Genotype leaf feeding was not correlated to the genotype borer parameters measured at grain harvest at Ottawa in 1991 and 1992, and Prescott in 1991 (Table 2.9). In 1991, the earlier seeding at Prescott resulted in uniform leaf feeding among the various genotypes which annihilated any correlation. Overall, the inbred A619 (Cobden) and CI31A (Ottawa and Prescott) had the lowest rating. These inbreds are the latest in maturity and were the most delayed in development at the time of infestation (5-8 leaves) compared to adapted short season genotypes (such as CG16, CK44 or hybrid which had 10-12 leaves).

Each local climatic condition and year induced various plant and pest adjustments which altered leaf feeding behaviour. The 1991 drought accelerated plant development and constrained the larva to feed quickly on succulent plant parts before they hardened (leaves, inside whorl, tassel bud, collar sheath, cob); whereas the

Table 2.8 **Mean leaf feeding rating (Guthrie *et al.* 1960) for pool genotypes at Cobden and Prescott (natural population) and Ottawa (artificial infestation) during the 1991 and 1992 seasons.**

Year	Cobden	Prescott	Ottawa	F value
1991	1.63	1.52	1.63	0.89^{ns}
1992	1.17^{a}	1.44^{b}	2.52^{c}	32.25^{*}

note: Data for each genotype are found in Appendix 2.5.

Means in a horizontal row do not differ significantly if followed by the same letters using SNK test, P<0.05.

Table 2.9 **Simple linear correlation between corn borer and genotypes parameters in 1991 and 1992 at Ottawa and Prescott.**

OTTAWA

		Leaf Feeding	Number Tunnels	Tunnel length	Number Larva
Corn Heat Unit	1991	0.05	-0.26*	-0.32**	-0.12
	1992	0.17	0.41**	0.44**	-0.42**
CHU ratio	1991	0.04	0.30*	0.36**	0.15
	1992	0.19	0.44**	0.48**	0.44**
Leaf Feeding	1991	--	0.13	0.10	0.13
	1992	--	0.10	0.2	0.19
Grain moisture	1991	-0.09	-0.48**	-0.55**	0.31**
	1992	-0.11	-0.53**	-0.53**	-0.46**

PRESCOTT

		Leaf Feeding	Number Tunnels	Tunnel Length	Number Larva
Corn Heat Unit	1991	0.11	0.09	0.11	0.10
	1992	0.30*	0.12	0.06	0.30*
CHU ratio	1991	0.13	0.07	0.09	0.10
	1992	-0.32**	0.15	-0.08	-0.34**
Leaf Feeding	1991	-	0.01	0.02	0.02
	1992	-	0.37**	0.20	0.47**
Grain moisture	1991	0.04	-0.25*	-0.29*	-0.12
	1992	0.36**	0.01	-0.01	0.06

Primary data are found in Appendix 2.5, 2.6, and 5.1.
Values with * and ** are significant at 5% and 1%, respectively.

wet conditions in 1992 increased genotype set back and larval mortality (larval population passes from 6 larvae/plant to 0.5 larvae/plant in August due likely to drowning and wash off the plants). Moreover, genotype characteristics, such as leaf toughness (Bergvinson 1993), leaf pubescence (causing neonate injury or starvation) and plant phytochemistry (Campos *et al.* 1989; Bergvinson 1993) may have altered the severity of the leaf feeding.

Leaf damage in eastern Ontario under-estimated genotype borer-resistance in both years based upon the larval populations and the total amount of damage observed at harvest. Consequently, selection for first-population borer resistance based solely on leaf damage remained problematic. The difficulty in field screening resides in the corn borer population-size (natural infestation), the voracity of the laboratory cultures (borer reared on a meridic diet for 10 generations) and the unpredictable weather conditions. The later determines the genotype rate of development (i.e., maturity vs locations and environment), control the corn borer impact [phenology (including voltinism), mortality (egg desiccation, larval drowning or washing off), developmental stage duration and behaviour], and the critical temporal relationship between plant and pest synchrony (fitness).

Larval behaviour: Mature larvae migrated into the lower section of the stalk regardless of the originating population's (starting at the whorl plant stage: June; after pollination stage: July; or blister stage: August population). Thus, by late August, 50% of the total recovery was collected in the basal 30 cm of stalk. At grain harvest, this percentage increased to 75% (Table 2.10) with the addition of the August population. The graphical representation of the percentage of the tunnel length in the basal 30 cm of stalk and the August mean temperature was positively correlated for both harvest periods (Figures 2.5 & 2.6), suggesting that August was a critical month for the borer to resume larval development. Moreover, while corn borer incidence and damage severity varied with years (Table 2.11), the larval distribution changed only slightly.

Table 2.10 Analysis of variance of the percentage of the corn borer larvae recovered below 39cm, between 40cm-ear and above the ear at grain harvest at Cobden, Prescott and Ottawa.

Height	Cobden	Prescott	Ottawa
0-39cm[a]	79.2 ±2.4	72.7 ±4.2	68.7 ±6.9
40cm-ear[b]	14.9 ±0.9	17.8 ±3.0	24.4 ±8.3
above ear[c]	5.8 ±1.4	9.6 ±1.2	6.9 ±1.4

Analysis of variance: $F=151.4^{**}$, df= 2

Means in a column do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Figure 2.5 Simple linear regression analyses of the tunnel length incidence (first 30 cm) at silage harvest against the average August temperature at each location.

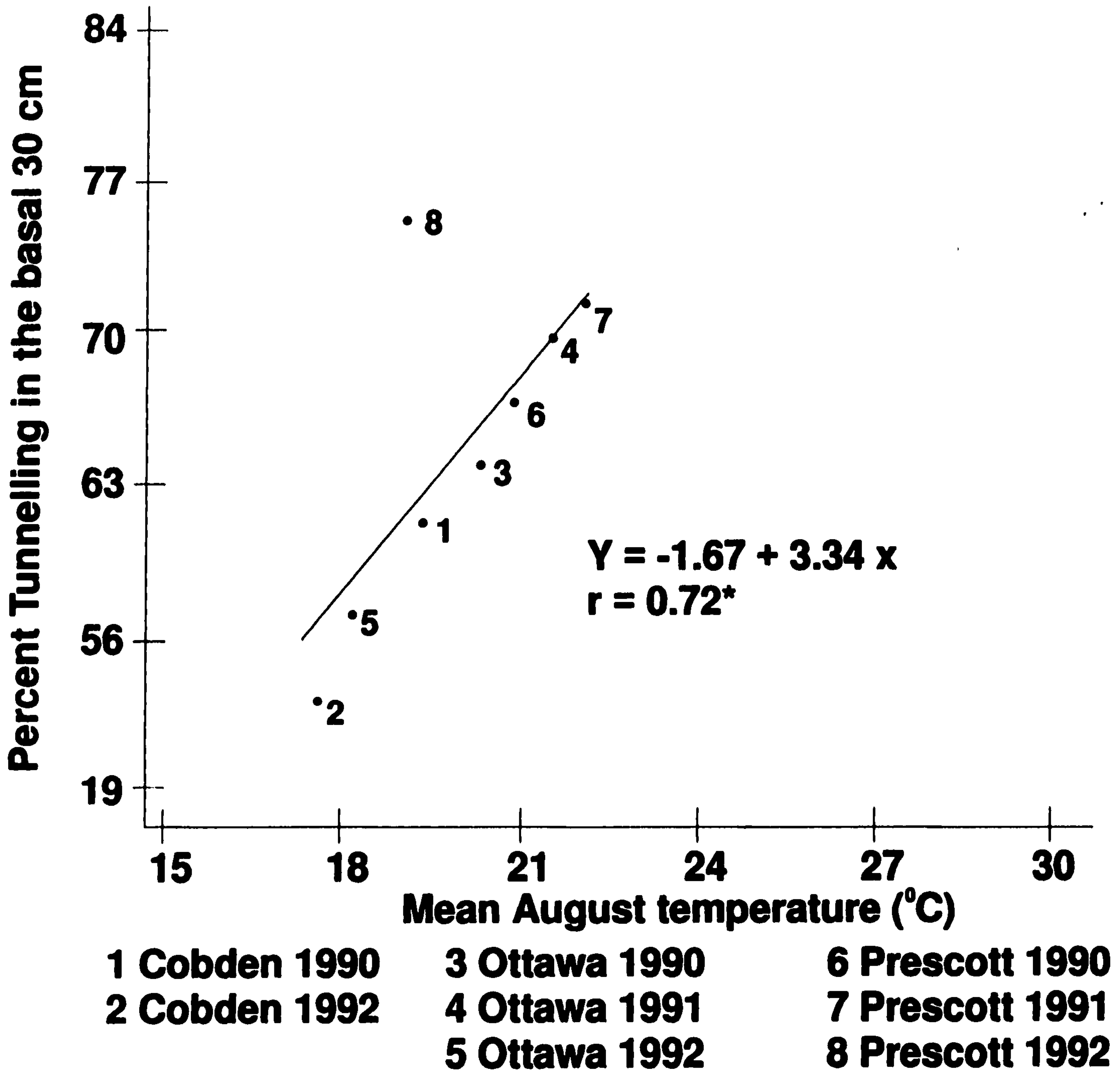

Percent Tunnelling in the basal 30 cm
84
77
70
63
56
19
15
18
21
24
27
30
Mean August temperature (°C)
8
7
4
6
3
1
5
2
Y = -1.67 + 3.34 x
r = 0.72*
1 Cobden 1990
2 Cobden 1992
3 Ottawa 1990
4 Ottawa 1991
5 Ottawa 1992
6 Prescott 1990
7 Prescott 1991
8 Prescott 1992

Figure 2.6 Simple linear regression analyses of the tunnel length incidence (first 30 cm) at grain harvest against the average August temperature at each location.

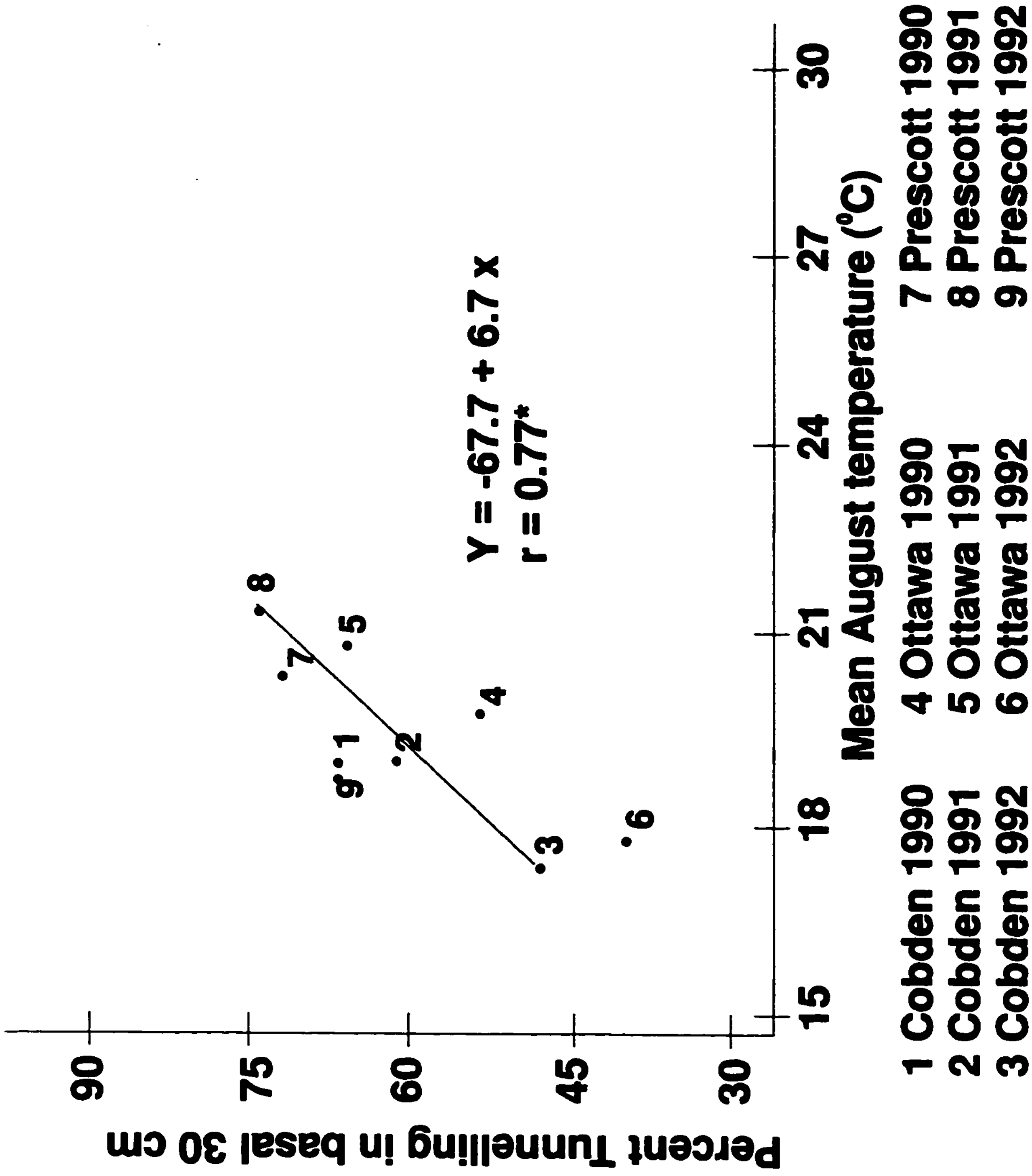

Percent Tunnelling in basal 30 cm
90
75
60
45
30
15
18
21
24
27
30
Mean August temperature (°C)
Y = -67.7 + 6.7 x
r = 0.77*
1
2
3
4
5
6
7
8
9
1 Cobden 1990
2 Cobden 1991
3 Cobden 1992
4 Ottawa 1990
5 Ottawa 1991
6 Ottawa 1992
7 Prescott 1990
8 Prescott 1991
9 Prescott 1992

Table 2.11 Comparison of the number of larva, the number of tunnels and the tunnel length during 1991 and 1992 climatic conditions (Student test).

	Number of		
	larva	tunnels	Tunnel length
Cobden	3.81•	2.93•	5.42•
Prescott	NS	NS	NS
Ottawa	6.39•	4.67•	6.83•

note: Primary data are found in appendix 2.6.

• $p<0.05$
NS not significant

Genotype resistance. All genotypes were injured by the corn borer pest. The distribution of the plant damage at grain harvest is represented in figure 2.7. Significantly more tunnel lengths were observed in the first 30 cm of stalk (Table 2.12). Concomitantly, the simple correlation for each location and genotype grouping between the number of tunnels and the tunnel length in the basal 30 cm of stalk and the total damage below the ear height were highly correlated (Table 2.13).

Genotype borer resistance within the inbred, hybrid and synthetic group varied with years and locations (Table 2.14). Because there was no significant difference between the three groups (Appendix 2.7) only the inbred lines were used to characterize borer susceptibility in Ottawa and Prescott (same genotype grown) because of their purity and wide range of maturity. The genotype damage was negatively correlated ($p<0.01$) with corn heat units, cultivar maturities, silage and grain moistures at both locations (Table 2.9). This indicates that some of the resistance/ tolerance was due to genotype maturity. The graphical representation of the genotype damage (tunnel length) plotted against the grain moisture (indicator of physiological maturity) (Figures 2.8 and 2.9) showed that the latest maturing genotypes[1] for eastern Ontario were consistently the least damaged (e.g. A619, B86, CI31A, DE811).

Each genotype grows differently. The inbred CG16 was susceptible to leaf feeding in July but escaped borer tunneling in August because of a poor root system that caused lodging prior to silking. The inbred CO266 is a genotype that produced numerous tillers. The main stalk was slightly attacked (first to develop) while the tillers were constantly damaged. The inbred DE811 escaped female ovipositon because the leaves were oriented upward. This exposed the eggs directly to the sun and resulted in greater mortality by desiccation. The inbred CI31A is a very late genotype for Ottawa-Prescott region and was unapparent to female motns in

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[1] 3000+ CHU, 81+ days to silking, high grain moisture.

Figure 2.7 **Vertical distribution, at grain harvest, of stalk tunnels for poolled genotypes at Cobden, Prescott, and Ottawa in 1991 and 1992.**

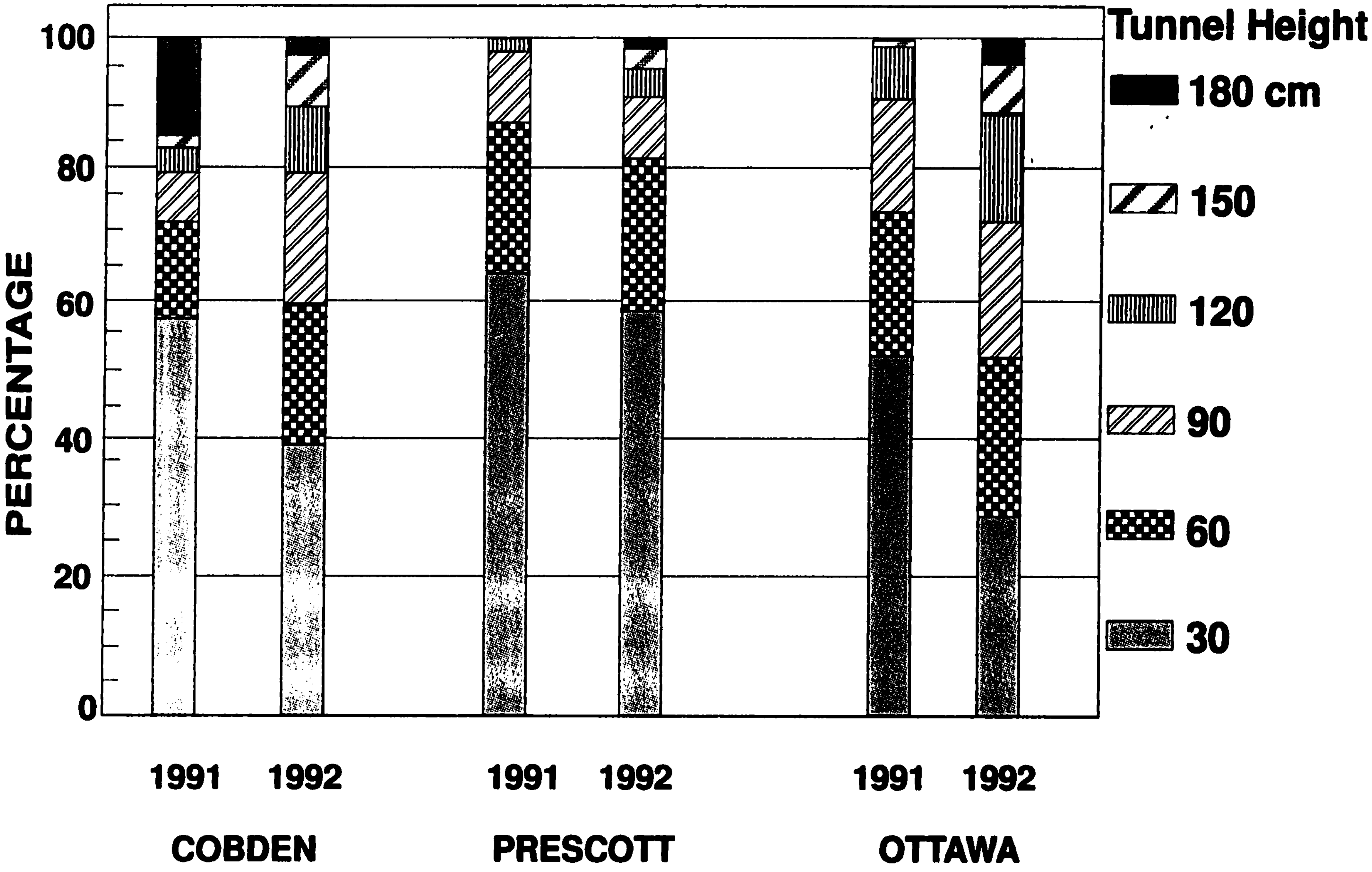

PERCENTAGE
100
80
60
40
20
0
1991
1992
1991
1992
1991
1992
COBDEN
PRESCOTT
OTTAWA
Tunnel Height
180 cm
150
120
90
60
30

Table 2.12 Analysis of variance of the tunnel height distribution.

	Tunnel distribution					
	below the ear height				above	
Height (cm)	30	60	90	120	150	180
Percent	51.1^{a}	20.2^{b}	13.6^{bc}	7.7^{c}	3.5^{c}	4.0^{c}

$F= 41.53^{**}$, df=5

Means in a row do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Table 2.13 Simple Pearson correlation at grain harvest.

Location	Year	Genotype grouping	Number of tunnels 30 cm vs ear height	Tunnel length 30 cm vs ear height
Cobden	1991	Inbred	0.963^{**}	0.935^{**}
		Hybrid	0.909^{*}	0.895^{*}
		Synthetic	0.962^{**}	0.948^{**}
	1992	Inbred	0.872^{**}	0.888^{**}
		Hybrid	0.843^{*}	0.879^{*}
		Synthetic	0.812^{**}	0.633^{ns}
Ottawa	1991	Inbred	0.946^{**}	0.944^{**}
		Hybrid	0.833^{*}	0.829^{*}
		Synthetic	0.936^{**}	0.955^{**}
	1992	Inbred	0.980^{**}	0.966^{**}
		Hybrid	0.942^{**}	0.929^{**}
		Synthetic	0.902^{**}	0.934^{**}
Prescott	1991	Inbred	0.984^{**}	0.984^{**}
		Hybrid	0.915^{**}	0.866^{*}
		Synthetic	0.898^{**}	0.922^{**}
	1992	Inbred	0.893^{**}	0.889^{**}
		Hybrid	0.879^{*}	0.880^{*}
		Synthetic	0.894^{**}	0.882^{**}

* $p < 0.05$
** $p < 0.01$

Table 2.14 F values and level of significance determined in one way analysis of variance of inbred, hybrid, synthetic, and pooled genotypes for European corn borer parameters in 1991 and 1992.

Cobden 1991 genotype	df	Number of tunnel		Total tunnel length		Number of larva	
		below ear	0-39 cm	below ear	0-39 cm	below ear	0-30 cm
Pooled	14	5.54^{***}	4.62^{***}	4.21^{***}	3.46^{***}	2.73^{***}	2.48^{***}
Inbred	7	5.66^{***}	4.52^{***}	3.25^{***}	2.44^{*}	3.48^{***}	2.97^{**}
Hybrid	2	1.20	0.50	2.11	1.97	0.26	0.19
Synthetic	3	5.61^{***}	8.55^{***}	3.30^{*}	9.55^{***}	2.96^{*}	3.23^{***}
Cobden 1992							
Pooled	19	2.92^{***}	2.45^{***}	2.93^{***}	2.46^{***}	3.23^{***}	1.85^{***}
Inbred	10	1.15	1.25	1.97^{*}	2.12^{*}	2.13^{*}	1.39
Hybrid	3	2.22	2.06	3.79^{**}	1.30	2.23	2.14
Synthetic	4	2.89^{*}	2.46^{*}	0.87	2.98^{*}	1.51	3.05^{*}

Values with *, **, *** are significant at $P<0.1$, 0.05, and 0.01, respectively.
Primary data are found in Appendix 2.6.

Table 2.14 (cont'd)

Ottawa 1991 genotype	df	Number of tunnel		Total tunnel length		Number of larva	
		below ear	0-39 cm	below ear	0-39 cm	below ear	0-39 cm
Pooled	22	16.10***	22.63***	14.34***	19.29***	4.65***	5.43***
Inbred	12	17.21***	21.89***	16.02***	21.98***	4.72***	5.74***
Hybrid	2	3.58*	3.17*	4.66**	3.10*	3.33*	1.30
Synthetic	6	15.15***	11.24***	14.64***	10.54***	1.65	0.81
Ottawa 1992							
Pooled	22	10.48***	12.52***	6.42***	7.48***	3.67***	4.38***
Inbred	12	12.35***	12.89***	8.82***	8.98***	3.91***	4.08***
Hybrid	3	2.23	1.48	1.94	1.09	2.15	0.89
Synthetic	6	10.99***	6.29***	6.92***	5.04***	1.36	1.35

Values with *, **, *** are significant at $P<0.1$, 0.05, and 0.01, respectively.
Primary data are found in Appendix 2.6.

Table 2.14 (cont'd)

Prescott 1991 genotype	df	Number of tunnel		Total tunnel length		Number of larva	
		below ear	0-39 cm	below ear	0-39 cm	below ear	0-39 cm
Pooled	19	3.54***	4.54***	3.58***	4.39***	2.94***	3.29***
Inbred	12	4.49***	5.50***	4.33***	4.86***	3.74***	3.88***
Hybrid	2	5.94*	13.17***	4.63	15.28***	5.80*	4.20
Synthetic	5	1.51	1.64	2.43	2.82	0.77	0.61
Prescott 1992							
Pooled	22	9.92***	7.45***	5.93***	3.46***	9.23***	7.85***
Inbred	12	10.46***	8.00***	6.73***	4.46***	10.32***	8.51***
Hybrid	3	3.54**	4.94***	6.19***	5.28***	7.40***	6.93***
Synthetic	5	10.08***	8.31***	9.98***	8.09***	5.05***	5.21***

Values with *, **, *** are significant at $P<0.1$, 0.05, and 0.01, respectively.
Primary data are found in Appendix 2.6.

Figure 2.8 Linear regression of the tunnel length against the grain moisture in Ottawa in 1991 and 1992. (each point represent a different maize genotype).

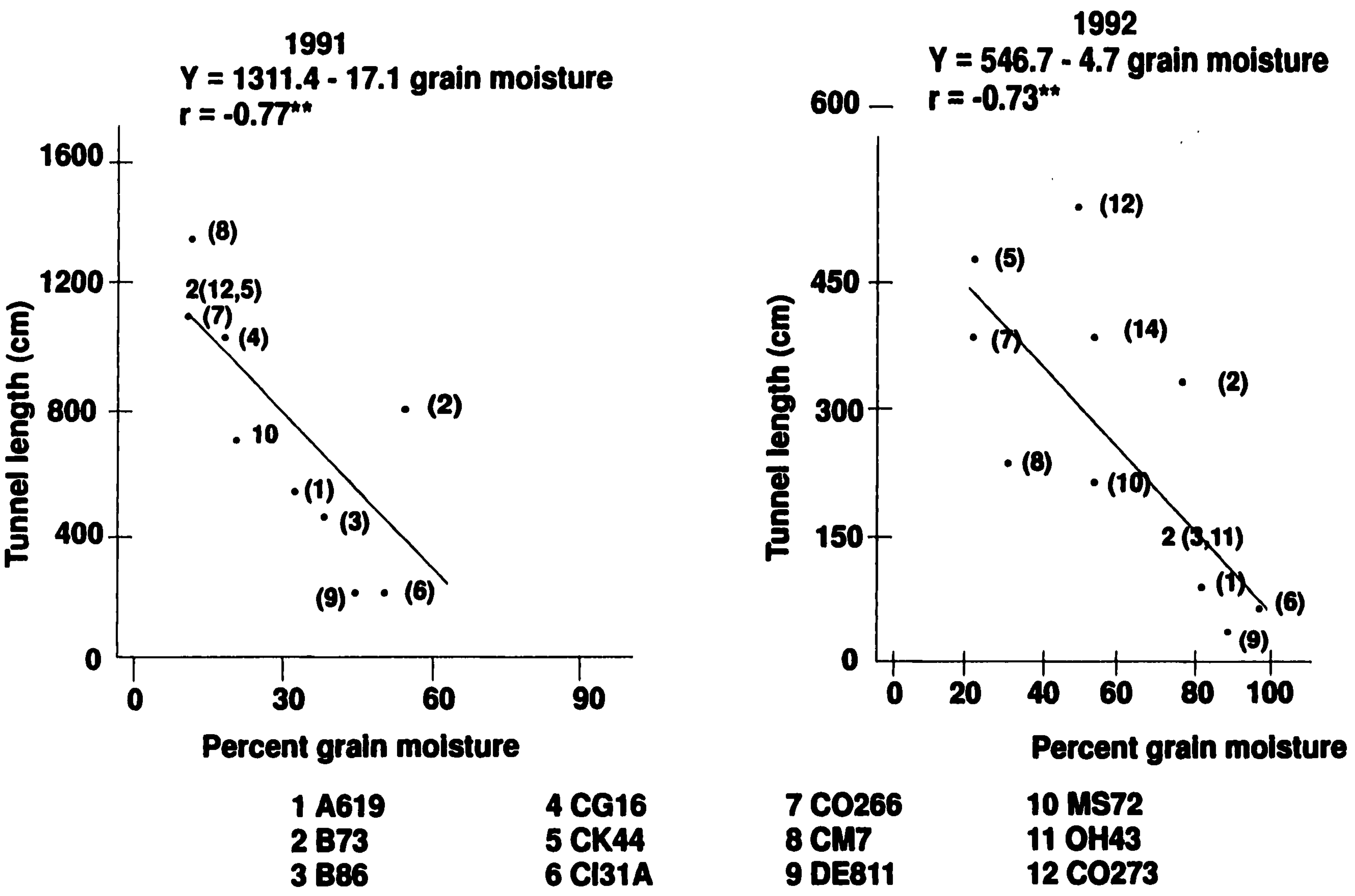
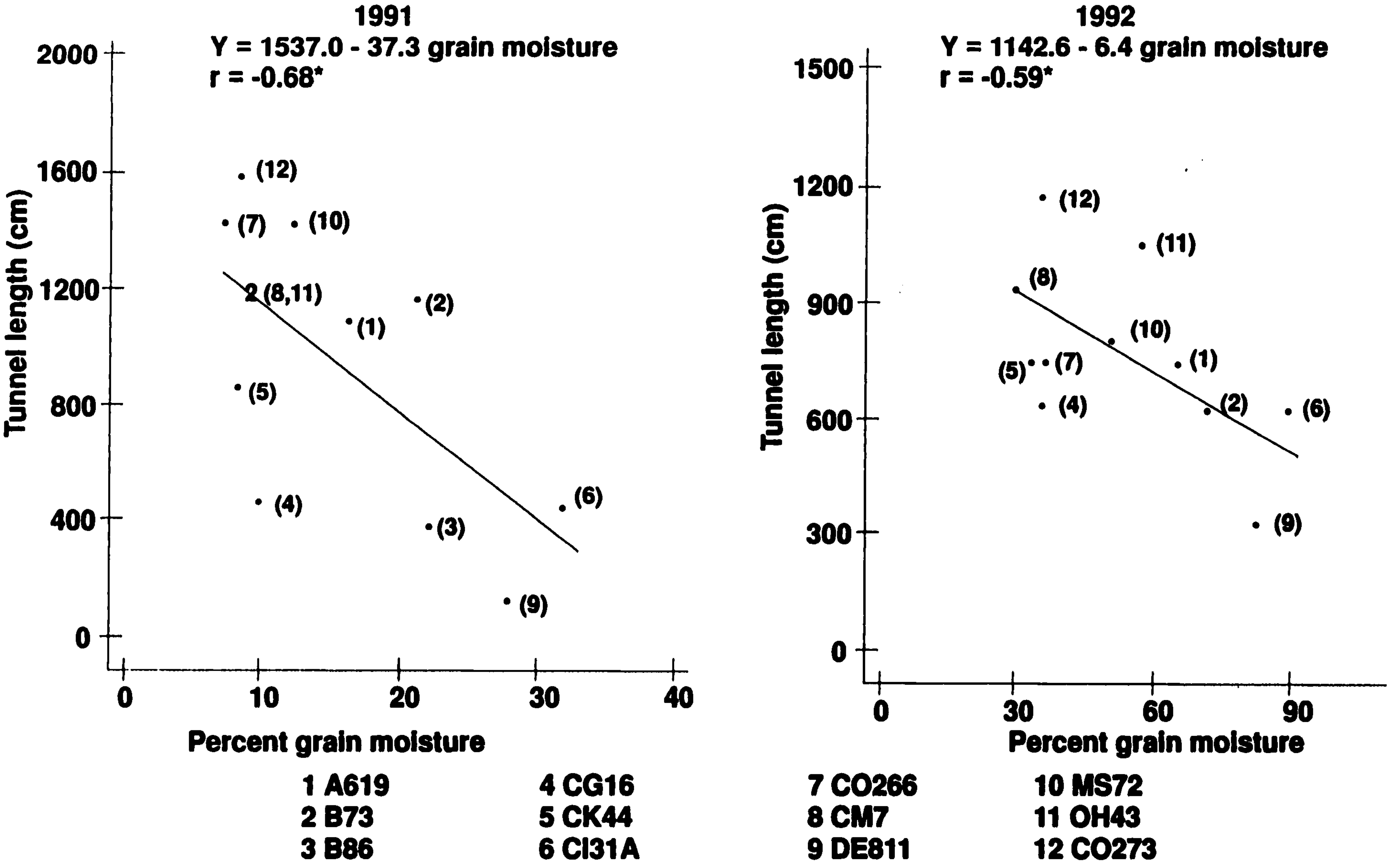

1991
Y = 1311.4 - 17.1 grain moisture
r = -0.77**
Tunnel length (cm)
1600
1200
800
400
0
0
30
60
90
Percent grain moisture
(8)
2(12,5)
(7)
(4)
(2)
10
(1)
(3)
(9)
(6)
1992
Y = 546.7 - 4.7 grain moisture
r = -0.73**
Tunnel length (cm)
600
450
300
150
0
0
20
40
60
80
100
Percent grain moisture
(12)
(5)
(7)
(14)
(2)
(8)
(10)
2 (3,11)
(1)
(6)
(9)
1 A619
2 B73
3 B86
4 CG16
5 CK44
6 CI31A
7 CO266
8 CM7
9 DE811
10 MS72
11 OH43
12 CO273

Figure 2.9 Linear regression of the tunnel length against the grain moisture in Prescott in 1991 and 1992. (each point represent a different maize genotype).


1991
Y = 1537.0 - 37.3 grain moisture
r = -0.68*
Tunnel length (cm)
2000
1600
1200
800
400
0
0
10
20
30
40
Percent grain moisture
(12)
(7)
(10)
2 (8,11)
(1)
(2)
(5)
(4)
(3)
(6)
(9)
1992
Y = 1142.6 - 6.4 grain moisture
r = -0.59*
Tunnel length (cm)
1500
1200
900
600
300
0
0
30
60
90
Percent grain moisture
(12)
(11)
(8)
(10)
(5)
(7)
(1)
(4)
(2)
(6)
(9)
1 A619
2 B73
3 B86
4 CG16
5 CK44
6 CI31A
7 CO266
8 CM7
9 DE811
10 MS72
11 OH43
12 CO273

July [8 leaf stage (60 cm) compared to control hybrid with 12-14 leaves (170 cm)]. This desynchronization permitted the inbred CI31A to escape the first generation attack. Inversely stalk damage during August increased while the plant was at the silk developmental stage. Other genotypes such as B86, BS9 and PRC03 are late varieties and have a thick and hard rind which protected the plant from stalk breakage until harvest.

Under the growing conditions prevalent in eastern Ontario, late genotypes cultivated out of their maturity zones were set back at time of corn borer oviposition in July which indicated an asynchrony between maize susceptible stages and corn borer phenological requirements. The maize and corn borer association was complicated by unpredictable weather conditions which modify the plant developmental rate and the phytochemical biosynthesis (Atkins *et al.* 1987), caused additional plant stress and affected the corn borer seasonal history including establishment (natural or artificial population), behaviour, voltinism and ultimately the amount of stalk damage.

Hybrid grain yields were negatively correlated with the number of tunnels (Figure 2.10). This is not surprising because hybrids are the result of crosses between parents with specific traits, whereas inbreds are selfed among themselves to preserve inbred traits. Consequently, the developed hybrid with improved yield performance, looses some of the desired parental traits (such as pests resitance). The inbred graph indicates that the grain yield was positively correlated with the number of tunnels (Figure 2.11). Thus, inbred with the lowest grain moisture and greatest number of tunnels had the highest yield, suggesting that the plant can tolerate some insect injury by increasing physiological activity and grain dry-down. On the contrary, the less damaged genotypes (B86 and CI31A) had good borer tolerance but were much too late for our environment and produced lower yield.

Figure 2.10 **Linear regression of hybrid grain yield to plant damage for the natural corn borer population at Prescott and artificial infestation at Ottawa.**

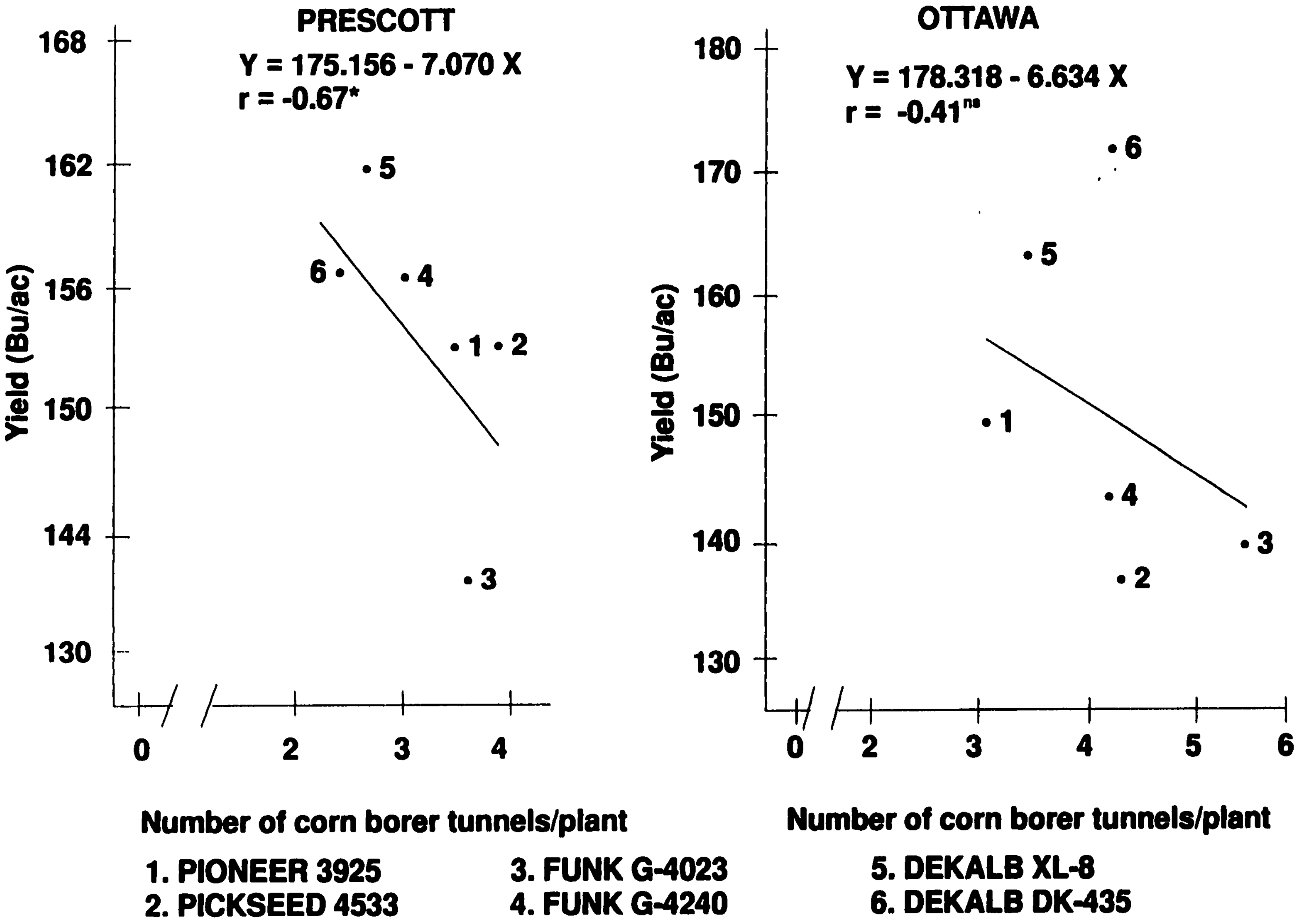
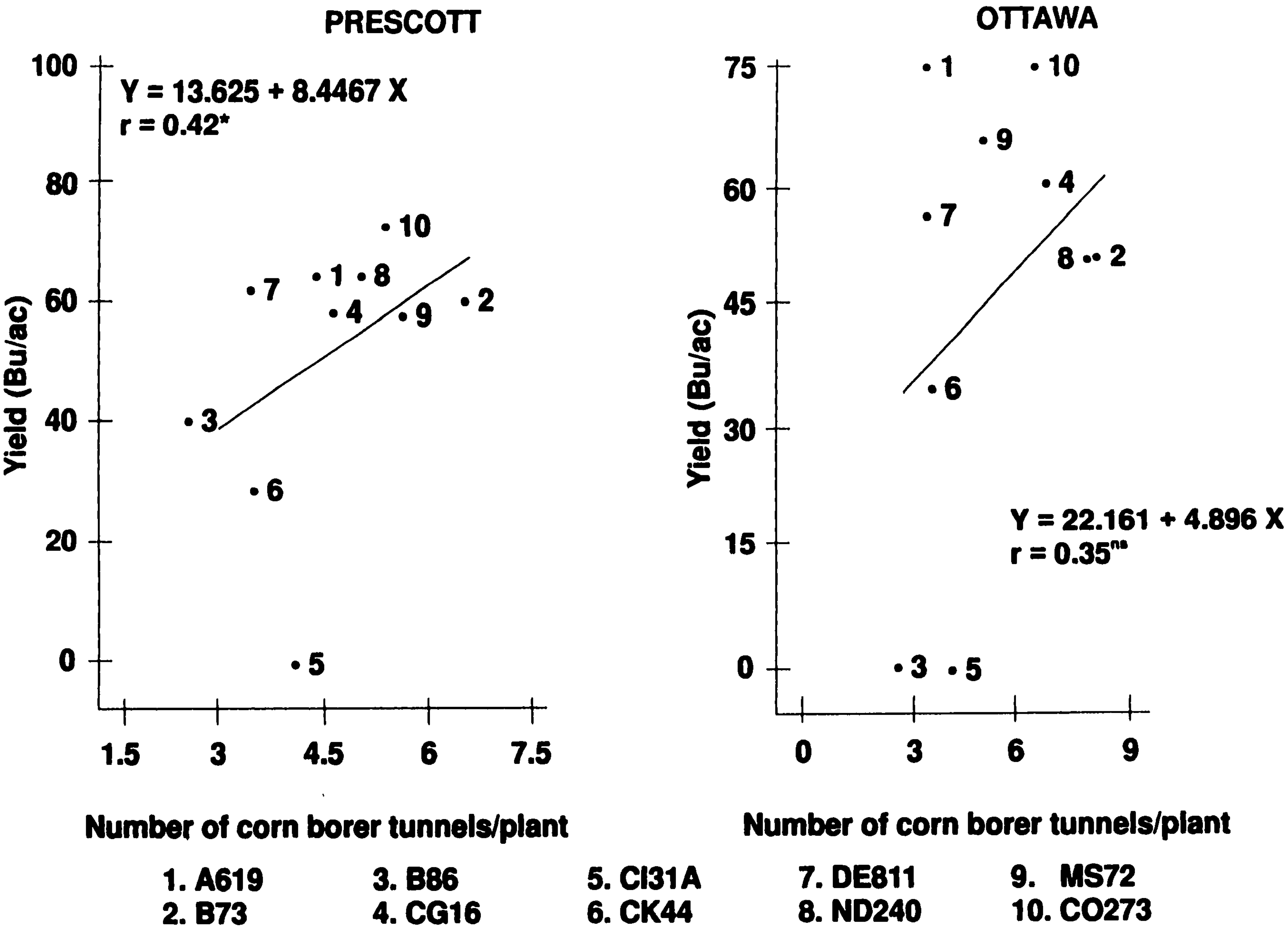

PRESCOTT
Y = 175.156 - 7.070 X
r = -0.67*
Yield (Bu/ac)
168
162
156
150
144
130
0
2
3
4
Number of corn borer tunnels/plant
OTTAWA
Y = 178.318 - 6.634 X
r = -0.41ns
Yield (Bu/ac)
180
170
160
150
140
130
0
2
3
4
5
6
Number of corn borer tunnels/plant
1. PIONEER 3925
2. PICKSEED 4533
3. FUNK G-4023
4. FUNK G-4240
5. DEKALB XL-8
6. DEKALB DK-435

Figure 2.11 Linear regression of inbred grain yield to plant damage for the natural corn borer population at Prescott and artificial infestation at Ottawa.


PRESCOTT
Y = 13.625 + 8.4467 X
r = 0.42*
Yield (Bu/ac)
100
80
60
40
20
0
1.5
3
4.5
6
7.5
Number of corn borer tunnels/plant
1
2
3
4
5
6
7
8
9
10
OTTAWA
Y = 22.161 + 4.896 X
r = 0.35ns
Yield (Bu/ac)
75
60
45
30
15
0
0
3
6
9
Number of corn borer tunnels/plant
1. A619
2. B73
3. B86
4. CG16
5. CI31A
6. CK44
7. DE811
8. ND240
9. MS72
10. CO273

CONCLUSION

In eastern Ontario, three corn borer populations occurred. Moreover, under exceptional climatic condition (such as 1991) a fourth flight was observed at the southern location while the July population underwent another generation in August.

New maize assessment methodology for European corn borer resistance is proposed based on percent plant-leaf damages, larval and tunnel distribution and the percent of undamage plants. The classical leaf rating developed by Guthrie *et al.* (1960) for U.S. corn belt did not apply to eastern Canada. The low leaf feeding rating observed in Eastern Ontario was a poor indicator of genotype 1st generation borer resistance because of the unpredictable climatic conditions during and after egg laying (natural or artificial infestation) and larval feeding behaviour which moved quickly to plant whorl to feed on yellow tissue and tassel bud. If leaf feeding assessment has to be conducted, it is greatly improved with the aid of the plant-leaf damage rating, which is based on quantitative characters rather than qualitative, for uniformity and rapidity.

The dissection of more than 2500 plants showed that 78% of the total tunnel length was located in the first 30 cm of stalk. This made possible to adequately evaluate genotypes for corn borer susceptibility. The data showed that physiological maturity, as determined by the grain moisture, affected host-pest synchrony and reduced European corn borer establishment and damage. Moreover, favourable temperature during August was significantly related to the tunnel length at silage and grain harvest. That period corresponded to overwintering preparation of the 2nd adult population (July) or completion of development for the 3rd population (August). The 1992 growing season may be misleading because of the early killing frost which reduced standing independently of corn borer damages.

Therefore, under eastern Ontario conditions, genotype selection for corn borer susceptibility was best determined at grain harvest, based on borer damage taking into account genotype maturity and plant stage events such as leaf appearance, silking date, cultural practice and pest behaviour.

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Chapter 3.

EPIDEMIOLOGY OF *FUSARIUM* STALK ROT IN RELATION TO LOCATION AND THERMAL REQUIREMENTS OF MAIZE GENOTYPES IN EASTERN ONTARIO.

INTRODUCTION

Fusarium rot was first reported in US in 1904 (Smith and Swingle 1904) and in Canada in 1943 (Gordon 1944). Fusaria species have long been associated with root, stalk and ear rot of maize (Christensen and Wilcoxson 1966; Francis and Burgess 1975; Gordon 1959; Kommedahl and Windels 1981; McGee 1988, Neish *et al*. 1983; Reid 1994; Sutton 1982). Among the *Fusarium* spp. causing stalk rot, *F. graminearum* Schwabe, *F. moniliforme* Sheldom, *F. subglutinans* (Wollenw. & Reinking) and *F. proliferatum* (Matsushima) were the most commonly reported (Neish and Legget 1981; Windels *et al*. 1988).

Stalk rot severity varies from year to year according to weather conditions, genotipic susceptibility, cultural practice, plant pre-disposition, mechanical injury, insect damage, and plant stress (Dodd 1980; Marasas *et al*. 1984; McGee 1988; Price 1984; Schneider and Pendery 1984; Smith and White 1988). It appears late in the growing season with early hybrids or inbreds exhibiting disease symptoms first (Young and Kucharek 1977; Whitney and Mortimore 1957).

In Ontario, where maize is the most important grain crop (Anon 1992), stalk rot may increase lodging, cause early stalk breakage, delay plant development, kill the plant prematurely, reduce ear size, induce poor grain quality, or reduce grain yield (Christensen and Schneider 1948, DeVay *et al*. 1957; Edward 1936; McKeen 1953; Smith and White 1988).

Plant breakage averaged 25-30% between 1936 and 1992 (OCPA 1937-1993) and was attributed indiscriminately to insects, fungi, or climatic conditions. Yield losses of 7.5% (Christensen and Wilcoxson 1966) and 16.2% (Hooker and Britton 1962) have been reported from the natural occurrence of stalk rot and an additional 3.1%-7.1% to the European corn borer larva (Godfrey *et al*. 1991).

The seasonal history of the European corn borer has been extensively studied. In chapter 2, a relation between climatological conditions and plant development, moisture at silage and grain, borer establishment and damage severity was determined. Moreover, healthy stalk (damage-free) and borer damage severity were negatively correlated with the grain moisture (indicator of genotype maturity). However, few studies have documented the seasonal *Fusarium* population and its synchrony with plant development.

Although *Fusarium graminearum* have been studied the most, this species is not the principal disease in all regions (Miller and Trenholm 1993). Moreover, temperature and moisture have been shown to influence the growth of all fungi including *Fusaria* (Magan and Lacey 1984). The present chapter focusses on the relation of stalk rot incidence to thermal ecotone zones and genotype maturity (as determined by the grain moisture) as well as determining the *Fusarium* complex in each of these ecotones. In particular, it is hypothesized that the location of the thermal ecotone in Ontario governs the stalk rot event.

MATERIALS AND METHODS

Baseline infections were determined on 10 genotypes also used for corn borer studies in the 3 locations. The stalk rot study was conducted during the 1991 and 1992 growing seasons at three locations: Cobden, Ottawa, and Prescott. Experimental sites were prepared according to farmer's practice, i.e., conventional tillage in Cobden, minimum tillage in Prescott, and flail (Ford lawnmower model 917), plowed and disced the following spring in Ottawa. Corn heat units were determined following the method of Major *et al*. (1976).

Twenty-two genotypes of maize representing three maturity groups: early [the inbreds CG16, CK44, CO266, CM7 and CO273; the hybrid Pioneer 3902; and the synthetics PRC-01 (SFP1), and PRC-02]; medium [the inbreds A619 and MS72; the hybrids Pioneer 3925, Pickseed 4533 and Dekalb DK-435; and the synthetic PRC-04]; and late [the inbreds B73, B86, CI31A, DE811 and OH43; and the synthetics PRC-03, BS9-C0 and BS9-C4] were selected for different degrees of susceptibility (Darrah 1985, Lamkey 1987, Bob Hamilton pers. comm.) to *Fusarium* and European corn borer (*Ostrinia nubilalis* Hübner). CI31A and DE811 were not planted at Cobden since this is beyond their maturity limit.

A split-plot experimental design with 4 replicates was used where genotype group (inbred, hybrid, or synthetic) was randomized to the main plot units and individual genotypes were randomized to the sub-plots units. Each sub-plot consisted of a single row (8 m long by 90 cm wide) of approximately 50 plants (24,000 plants/acre). Data on the occurrence of *Fusarium* spp. and determination of the *Fusarium* complex of the stalk was obtained at silage (mid-September) and grain harvest (late-October). The four end plants of each row were discarded and five plants (i.e., every third one) for a total of 25 plants were dissected for each of the harvest period.

Epidemiology and infection

Isolation of the *Fusarium* species and determination of incidence was conducted from May (planting) to October (harvest). Weekly, *Fusarium* aerial dispersion was determined bi-monthly using pentachloronitrobenzene culture plates [PCNB: selective medium for *Fusarium* spp. (Nash and Snyder 1962)] exposed for 10 minutes in the field. Samples of maize residues (stubble with and without borer damage) and new seedlings (leaf tissue, undamaged pith, borer and tunnels) were aseptically collected with forceps (dipped in 75% ethanol) and placed in plastic sterile capsules [Sarstedt (1.5 ml, 39x10 mm)]. Samples were stored in a freezer at -20^{0}C until processed for *Fusarium* spp. identification.

Weekly in 1991 and 1992, 100 random stubbles were collected for European corn borer studies from which a subsample of 10 insect damage-free residues and 30 tunneled plant-tissues were used for *Fusarium* research. Starting in early-July and up to late-August, 10 damage-free and 30 young seedlings with borer damage were dissected and *Fusarium* samples taken. Leaf sheath, larvae, and stalk tissues were plated. At silage and grain harvest, leaf, stalk and larval samples from 10 plants per genotype and replicate were sampled for *Fusarium* determination. In both years, *Fusarium* incidence was derived from the total platings and statistical analysis conducted after arcsin square root transformation of the percent incidence (Little and Hills 1976).

Isolation and identification

The samples were plated on PCNB medium amended with streptomycin sulfate (1.0 g/L) (Nash and Snyder 1962, Nelson *et al.* 1983) in 10 cm diameter petri dishes. Plates were incubated at room temperature (25^{0}C) under natural daylight for 5 to 7 days. Colonies of *Fusarium* growing from the sampled pieces were transferred to a synthetic nutrient agar (SNA) medium in 6 cm diameter petri dishes, on which a piece of sterile filter paper (1 cm^2 triangular) had been deposited (Nirenberg 1976). SNA culture plates were incubated under 4 fluorescent tubes (Sylvania Cool White (F40 CW)) with one black light (Sylvania Black Lite Blue (F40 BLB)) in the center, at 25^{0}C under 12h L:12h D for approximately 14 days. Cultures that developed on SNA were examined using a phase contrast microscope (Zeiss model D-7082, Axioskop) and identifications made with the aid of an illustrated morphological manual of *Fusariua* species (Nelson *et al.* 1983) and a computer-based synoptic program developed by K. Seifert (Agriculture Canada).

Statistical analyses using SAS version 6.03 (SAS, 1988) were performed after the transformation of the percentage data using arcsin square root of the percent stalk rot incidence (Little and Hills 1976) to satisfy the assumption of the general linear model. Comparision of the means within varieties and between treatments was only carried out if the treatment F-ratio was significant using Student-Newman-Keul's test.

RESULTS AND DISCUSSION

The incidence of *Fusarium* stalk rot in three maize ecotones is summarized in table 3.1. There was a significant difference in the percentage of stalk rot between locations and years (Table 3.2). Incidence of *Fusarium* stalk rot in Cobden, Ottawa and Prescott attained 46%, 46%, and 37% respectively, in 1991, whereas in 1992, stalk rot fell to 18% in Cobden, while at Ottawa and Prescott it decreased to 39% and 33% respectively. These extreme climatic conditions (1991 drought vs 1992 wet and cold temperature) affects *Fusarium* epidemiology (Sutton 1982) and European corn borer establishment, *Ostrinia nubilalis* Hübner (Caffrey and Worthley 1927). The latter bore into the stalk making entries for infection (Christensen and Wilcoxson 1966). Concomitantly, the plant growth, regardless of the maturity, is also affected by the environmental conditions (Hartman *et al.* 1981). However the genotypes have relative susceptibility that are similar regardless of environmental conditions. While seasonally warm temperature influences plant development and disease cycle, *Fusarium* infections depends on: 1) availability of spores from the previous year; 2) species climatic requirement including humidity and temperature to initiate epiphytic inoculum (Kommedahl and Windels 1981); and 3) synchrony between the presence of fungal inoculum and plant injury caused by insects or weather such as wind. Concurrently, the genotype by year interaction was highly significant (Table 3.3). This agreed with Reid (1994) and Smith and White (1988) who demonstrated the inherent susceptibility of most hybrids to *Fusarium* pathogen which varies with locations or years. The drought conditions in 1991 and the excessive rain and cooler temperature in 1992 could have reduced spore dispersal due to the incapacity of some fungi to become air borne (Burgess 1981). Over the course of the study, genotypes in the warmer Ottawa and Prescott locations attained maturity sooner leading to earlier breakdown of pith tissue than at Cobden, a cooler site and led to a greater incidence of stalk rot (Appendix 3.1). The extended growing season in the southern locations permitted a better synchrony with fungal spore,

Table 3.1 Mean incidence of all *Fusarium* spp. recovered for all maize genotypes within a maturity group at three locations in 1991 and 1992 (Data expressed as percent of stalks infected with ± standard error in parenthesis).

Genotype maturity	1991			1992		
	Cobden	Ottawa	Prescott	Cobden	Ottawa	Prescott
early	51.6 (6.11) (n=160)	52.1 (3.96) (n=282)	42.0 (3.26) (n=274)	20.6 (4.68) (n=112)	42.1 (6.70) (n=185)	36.2 (3.64) (n=220)
medium	47.8 (13.23) (n=153)	47.4 (4.68) (n=230)	37.1 (6.24) (n=186)	14.6 (2.48) (n=100)	35.2 (3.01) (n=134)	33.5 (4.86) (n=120)
late	15.4 (5.1) (n=111)	39.0 (4.37) (n=272)	30.7 (5.64) (n=218)	17.7 (6.06) (n=80)	40.8 (5.62) (n=115)	29.7 (2.89) (n=128)
overall	46.4	45.9	36.6	17.6	39.4	33.0

Primary data are found in Appendix 3.1.

maturity

early : Cobden 1991= 4 genotypes; 1992 and Ottawa and Prescott 1991 and 1992= 7 genotypes

medium: Cobden 1991 and 1992= 4 and 5 genotypes, respectively. Ottawa and Prescott 1991 and 1992= 6 genotypes.

late : Cobden 1991 and 1992= 4 genotypes
Ottawa and Prescott 1991 and 1992= 9 genotypes.

Table 3.2 Analysis of variance of the percentage of *Fusarium* stalk rot occurrence as a function of locations and years of study.

	dF	F
Locations	2	5.67*
Years	1	8.21*
Locations by years	2	2.14ns

* P<0.05
ns not significant

Table 3.3 Analysis of variance of the percentage of *Fusarium* stalk rot occurrence as a function of the genotypes and years of study.

	Cobden		Ottawa		Prescott	
	df	F	df	F	df	F
Genotype	9	3.79^{**}	21	1.54^{ns}	20	2.12^{**}
Year	1	62.67^{**}	1	13.43^{**}	1	0.54^{ns}
Genotype by year	9	2.07^{**}	21	2.50^{**}	20	2.02^{**}

**: $P<0.01$
ns: not significant

a longer exposure to favourable incubation, colonization and stalk invasion period prior to killing frost occurrence. Furthermore, thegenotype stalk rot incidence, within a location, increased as the season progressed (silage vs grain harvest).

1991 study: The results of the mycological examination of maize residues and new seedling tissue revealed the seasonal recovery of various *Fusarium* isolates associated with stalk rot (Table 3.4). *Fusarium moniliforme*, *F. sporotrichioides*, and *F. equiseti* were recovered at the 3 locations during the entire growing season. *F. culmorum* was recovered in the fall at Cobden and Ottawa, and all year round at Prescott. *Fusarium oxysporum*, *F. sambucinum*, *F. avenaceum* and *F. graminearum* were recovered in the spring from corn residues beginning on week 31 (i.e., first week of August) on the new seedling (leaf sheath and tunneled pith dug by the borer). Other less common *Fusarium* species encountered in the stalk were observed in the spring and later in the fall.

The hot seasonal temperature favoured the rapid development of the vegetative plant stages, caused poor synchrony between pollen shedding and silking, and early dry down of the pith tissue which lessens plant-fungies synchrony. As a result, in late August, early maize genotypes attained the kernel black layer stage and became the first contaminated by *F. moniliforme*, *F. oxysporum*, *F. equiseti* and *F. sporotrichioides*. The mycological identification revealed that *F. moniliforme* was detected from twenty genotypes, with the exception of DE811 and PRC03 (Table 3.5). *Fusarium graminearum* was recovered from early varieties (CG16, CK44, CO266, CO273, FRH, Pioneer 3925, Pickseed 4533 and PRC02) and 2 medium-late inbreds (A619, B73) at the southeast locations. Stalk rot incidence was low in B86, CI31A, DE811, OH43, FRH, DK435, PRC02, PRC03, PRC04, BS9 cycle 0 and cycle 5 because some of these are corn borer resistant and therefore had fewer entrance holes which possibly could have prevented the *Fusarium* introduction; and they are late maturity genotypes for our region, i.e., 2900+ CHU.

Table 3.4 Seasonal *Fusarium* recovery in 1991.

Cobden

Fusarium spp.	Julian week 17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	41
	-----debris----------------->										<------new seedling------->								
avenaceum			x												x			x	x
culmorum															x				x
graminearum	x		x		x										x				x
equiseti	x		x		x		x						x		x	x		x	x
moniliforme	x		x		x										x	x		x	x
oxysporum					x										x			x	x
sambucinum			x		x													x	x
subglutinans					x										x				
sporotrichioides	x				x								x		x			x	x

Ottawa

	Julian week 18	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	39	41	48
	----debris------------>								<-----------new seedling----------->											
avenaceum		x																x		
culmorum	x		x													x	x	x		
graminearum																x				x
equiseti	x	x	x				x						x		x		x	x		x
moniliforme	x	x	x				x				x				x	x	x	x		x
oxysporum	x																	x		
sambucinum	x			x											x		x			x
sporotrichioides	x	x		x		x					x					x		x		x

Table 3.4 (cont'd). **Seasonal *Fusarium* recovery in 1991.**

Prescott										**Julian week**										
***Fusarium* spp.**	**15**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**	**29**	**30**	**31**	**32**	**33**	**34**	**41**	**42**
	---------debris------------>										<---------new seedling------->									
avenaceum												x			x			x	x	
culmorum	x	x					x	x								x			x	x
graminearum	x	x	x			x	x												x	
equiseti	x	x	x			x	x				x	x		x	x		x	x	x	x
moniliforme	x	x												x						
oxysporum			x			x									x			x	x	x
sambucinum						x												x	x	
subglutinans			x								x	x			x			x	x	x
sporotrichioides							x								x		x	x	x	

Table 3.5 Major *Fusarium* isolates recovered from different maize genotypes in 1991 and 1992.

	moniliforme		*oxysporum*		*graminearum*		*sporotrochioides*		*avenaceum*		*equiseti*	
	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992	1991	1992
early												
CG16	X	X	X	X	X		X	X			X	X
CK44	X	X	X	X	X		X		X		X	X
CO266	X		X	X	X			X			X	X
CM7	X	X	X	X				X	X		X	X
CO273	X	X	X	X	X		X	X			X	X
PRC01	X	X	X	X		X					X	X
PRC02	X	X	X	X	X			X		X	X	X
medium												
A619	X	X	X	X	X		X				X	X
MS72	X	X	X	X							X	X
FRH	X	X	X	X	X			X			X	X
3925	X	X	X	X	X			X		X	X	X
4533	X	X	X	X	X					X	X	X
Dk-435	X	X	X	X		X					X	X
PRC04	X	X	X				X	X		X	X	X
late												
B73	X	X	X	X	X					X	X	X
B86	X	X	X	X			X				X	X
CI31A	X		X	X				X	X		X	X
DE811		X	X	X			X		X		X	X
OH43	X	X	X	X			X	X			X	X
PRC03		X	X					X		X	X	X
BS9C0	X	X	X	X				X			X	X
BS9C5	X	X	X	X				X			X	X

For each location, the *Fusarium* incidence was inversely related to genotype grain moisture, i.e., state of maturity (Table 3.6, Figure 3.1). In 1991, early genotypes had a lower incidence of stalk rot at Prescott. This may be because of very rapid corn development and dry-down of pith tissue which reduced the plant-fungal synchrony and colonization period, therefore reducing genotype susceptibility. Concurrently, stalk rot incidence in the late maturing genotypes diminished at all locations probably because of the host-plant physiological activity which protected the stalk from the infection and the spread of the pathogen into the host. For these genotypes, the maturity was attained later and the stalk remained for a longer period of time physiologically active which altered its sensitivity to fungal inoculum.

1992 study: The 1992 growing season was characterized by cool, wet weather and fewer hours of sunshine than normal (Bootsma and Brown 1993). *Fusarium culmorum*, *F. moniliforme*, *F. sporotrichioides*, and *F. equiseti* were recovered all season long whereas *F. oxysporum*, *F. sambucinum*, *F. avenaceum*, and *F. graminearum* were recovered from corn residues in the spring and beginning on week 31 on the new seedling (leaf sheath and stalk damages)(Table 3.7).

Between May and August, few heat units were accumulated monthly which, combined with the excessive amount of rain, delayed silking stage and reduced borer establishment. Under these conditions, less insect damage was observed which lessened opening to fungi and partly explains the lower incidence of stalk rot. In addition, at that time, stalks were physiologically active to fulfill silking-filling needs and were perhaps less receptive to the colonization phase. In September, temperature returned to seasonal values, while in October, very few heat units were accumulated. As a result, in Cobden, the genotypes attained the blister-milk stage before being killed by the frost (October 6) whereas in Ottawa and Prescott most genotypes were at the dough stage and a few attained the dent stage.

Table 3.6 *Fusarium* incidence as a function of genotype maturity at Ottawa and Prescott in 1991-1992.

Ottawa

Maturity	Mean incidence
Late	37.5a
Medium	44.0a
Early	54.4b

Analysis of variance	Df	F
Maturity	2	8.08**
Year	1	12.44**
Maturity*year	2	0.78ns

Prescott

Maturity	Mean incidence
Late	31.9a
Medium	36.9ab
Early	42.4 b

Analysis of variance	Df	F
Maturity	2	3.63*
Year	1	0.38ns
Maturity*year	2	0.93ns

note: Primary data are presented in Appendix 3.1.

Means in a column do not differ significantly if followed by the same letters using SNK test, P<0.05)

* p<0.05

** p<0.01

ns not significant

Figure 3.1 Scatter diagram showing the relationship between the percentage of *Fusarium* incidence and the percentage of grain moisture for each inbred genotype at each location in 1991.

Table 3.7 Seasonal *Fusarium* recovery in 1992.

Cobden

	Julian week																
Fusarium spp.	22	23	24	25	26	27	28	29	30	31	32	33	34	36	37	40	44
	--debris>	<------------					debris/seedling										----------------->
avenaceum		x					x		x	x			x	x	x	x	x
culmorum	x	x		x	x	x	x			x			x	x			
graminearum			x	x		x				x		x	x	x	x	x	x
equiseti	x	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x
moniliforme	x	x	x	x	x	x	x		x	x	x	x		x		x	x
oxysporum				x							x	x		x	x	x	x
sambucinum										x		x	x	x	x	x	x
subglutinans			x	x							x			x		x	
sporotrichioides	x	x	x	x	x	x	x			x				x	x	x	x

Ottawa

	Julian week																	
	19-	22	23	24	25	26	27	28	29	30	31	32	33	34	36	37	39	43
	--debris->		<------------					debris/seedling										----------------->
avenaceum	x												x	x		x	x	x
culmorum	x	x	x		x			x					x	x		x		
graminearum					x	x	x	x		x						x	x	x
equiseti		x	x		x	x	x	x	x	x	x		x	x		x	x	x
moniliforme	x	x	x		x	x	x	x	x	x	x		x	x		x	x	x
oxysporum					x							x				x	x	x
sambucinum									x			x				x	x	x
subglutinans																	x	x
sporotrichioides		x	x		x	x	x					x		x		x	x	x

Table 3.7 (cont'd). Seasonal *Fusarium* recovery in 1992.

Prescott

	Julian week																		
Fusarium spp.	17	20	22	23	24	25	26	27	28	29	30	31	32	33	34	36	37	39	42
	--debris->			<-------------debris/seedling----------------->															
avenaceum	x	x										x	x	x	x	x	x	x	x
culmorum	x	x	x		x	x	x		x			x	x				x		
graminearum	x	x	x			x	x					x	x			x		x	x
equiseti	x	x	x	x	x	x	x		x	x		x	x	x	x	x	x	x	x
moniliforme	x	x	x	x	x		x		x	x			x	x	x			x	x
oxysporum	x											x	x	x	x	x	x	x	x
sambucinum	x	x		x								x	x	x	x	x	x	x	x
subglutinans		x	x		x							x	x	x	x		x	x	x
sporotrichioides		x	x		x				x			x	x	x	x	x	x	x	x

The mycological recovery in 1992 indicated that *Fusarium moniliforme, F. oxysporum and F. equiseti* were recovered from most genotypes; *F. sporotrichioides* from 13 out of 23 genotypes; and the other fungal species were isolated occasionally (Table 3.5). The relatively low incidence of stalk rot caused by *F. graminearum* might be explained by: 1) the specific climatic requirement of this species; and 2) the shorter maturing period from physiological maturity to harvest in eastern Ontario despite its isolation from corn debris (post-harvest) from December to the following spring.

The linear regression showed that the percentage of *Fusarium* stalk rot diminished with the increase in genotype moisture (Figure 3.2). Stalk rot incidence decreased significantly at Cobden because of unfavourable conditions that prevented fungal development between silage and grain harvest, and combined with freezing temperatures that kill the plant prematurely and kill pre-overwintering macroconidia (Miller pers. comm.). Overall, The genotypes CG16, Pickseed 4533 and PRC02 were less susceptible at Cobden and Ottawa than at Prescott because of the reduced exposure to the fungi colonization period and frost-free period prior to infectious phase.

CONCLUSION

These results show the dynamic nature of the fungi due to the climatic/location conditions. Over the 2 years, four primary species, *Fusarium culmorum, F. equiseti, F. moniliforme* and *F. sporotrichioides* were recovered all year long from plant residues and new planting; concomitantly with soil fungi species (*F. avenaceum, F. equiseti, F. oxysporum*) from all cultivars tested. These soil fusaria may trigger *Fusarium* rot development by: 1) augmenting plant stress; 2) weakening the stalks which increases plant susceptibility to lodging or breakage prior to harvest; 3) increasing genotype susceptibility to more competitive fungi such as *F. moniliforme, F. culmorum, F. sporotrichioides*, or *F. graminearum*; or 4) initiating the early rotting of the pith tissue which explained the shift from soil borne fungi to more pathogenic fusaria between silage and grain harvest. Once the pathogen has

Figure 3.2 Scatter diagram showing the relationship between the percentage of *Fusarium* incidence and the percentage of grain moisture for each inbred genotype at each location in 1992.

begun infection, invasion between internodes is delayed solely by the vitality of the host cells which was demonstrated by the augmentation of stalk rot between silage harvest and grain harvest.

It was also demonstrated that, at each location, stalk rot incidence was inversely related to genotype grain moisture (maturity). Thus, when comparing similar genotypes among the three locations (e.g., CG16, CK44), the stalk rot incidence increased from a north to south gradient confirming the advanced genotype development and maturity at the southern site, and better synchrony between fungi, plant predisposition and epiphytic conditions to initiate stalk rot symptoms.

This study was conducted using the Food and Agriculture Organization (FAO) maize maturity index (100-800) in a region of 100-500 maturity units. It demonstrated that the earlier maturing genotypes were the first to be infected by *Fusarium*, and stalk susceptibility increased as the harvest season progressed, where the importance of conducting stalk rot rating in late-October (grain harvest) but before repetitive sub-zero temperatures occurred, to also account for late-genotypes development. In order to determine the stalk rot mechanism of infection, I will demonstrate in chapter 4 that the *Fusarium* mode of dispersal played an important rôle in the rot incidence.

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CHAPTER 4.

ANALYSIS OF *FUSARIUM* SPECIES ASSOCIATED WITH STALK ROT OF MAIZE (*ZEA MAYS* L.) IN RELATION TO THEIR MODE OF DISPERSION IN EASTERN ONTARIO.

INTRODUCTION

Fusarium fungi are the most common and the most severe causal agents of maize root, stalk, and ear rot (Christensen and Wilcoxson 1966; Francis and Burgess 1975; McGee 1988; Neish *et al.* 1983; Sutton 1982). This fungus has been reported in Australia (Francis and Burgess 1975); Eastern and Western Europe (Cassini 1981, Maric 1981); United States (Anderson 1987; Christensen and Wilcoxson 1966, Kommedahl and Windels 1981; Young and Kucharek 1977); and Canada (Gordon 1959; McKeen 1951, 1953; OCPA 1937-1993; Sutton 1982). *Fusarium graminearum* Schwabe, *F. moniliforme* Sheldom, *F. subglutinans* (Wollenw. & Reinking) and *F. proliferatum* (Matshushima) are the most frequently reported species causing maize stalk rot (Windels *et al.* 1988). Stalk rot disease may: 1) kill the plants prematurely and reduce yields (Christensen and Schneider 1948, Edward 1936; Francis and Burgess 1975; Smith and White 1988; Wilcoxson 1962); 2) increase lodging and incite early stalk breakage (Edward 1936); 3) diminish grain quality (Christensen and Schneider 1948; DeVay *et al.* 1957); 4) produce smaller ears (McKeen 1953); or 5) retard plant maturity which can increase plant susceptibility to disease (McKeen 1953).

Each *Fusarium* species has particular climatological requirements. Stalk rot severity varies with weather, hybrid susceptibility, cultural practices (crop rotation, surface residue, fertilization amendment), plant pre-disposition (e.g. grain contamination), environmental stress (plant density, water deficiency), injury (mechanical, animal), and stalk strength (Dodd 1980; Marasas *et al.* 1984; Price 1984; Schneider and Pendery 1984; Smith and White 1988). That is why disease significance usually peaks late in the growing season. Moreover, the extended warm and wet weather late in the growing season may also provide conditions that favor colonization by secondary *Fusarium* species such as *F. graminearum* (Francis and Burgess 1975) and cause rot synergism.

In Canada, maize is cultivated in Ontario and Quebec (primary producers of corn), on Prince Edward Island, in Manitoba and Alberta (Anon 1992). The Canadian maize program encompasses adaptation to northern latitude, earliness, and pest resistance (insects & fungi). The province of Ontario with 2350 to 3400 corn heat units (CHU) is divided into 8 heat unit zones (OCPA). The growing season in the eastern region (Ottawa area) is roughly 15 days shorter and 700 CHU less than the southern zone. Therefore, inbred developed at the Eastern Cereal and Oil Research Centre in Ottawa are suitable for Ontario (2350-3400 CHU), Quebec (2500-2700 CHU), Alberta (2500 CHU), Manitoba (2500 CHU) and Prince Edward Island (2400 CHU), as well as similar environments in Europe.

In Ontario, plant breakage averaged 25-30% of the crop (OCPA 1937-1993) and has been attributed indiscriminately to insects and fungal rot. Natural occurrence of stalk rot caused yield losses of 7.5% to 18.7% (Christensen and Wilcoxson 1966, Cook 1978, Hooker and Britton 1962) whereas stalks artificially inoculated with *F. graminearum* and *Diplodia maydis* (Berk.) showed a reduction of 17% (Wilcoxson 1962). Yield losses are complex to calculate because of the confounded incidence caused by natural infection in control plots, the difficulty of comparing inoculated vs uninoculated plots, and the fact that yield losses are based on hand-harvested yield and do not included losses due to lodging or ear rots (Smith and White 1988).

In Chapter 3, I determined the fungal epidemiology of nine *Fusaria* species in three representative ecotones (2400, 2700, 2850 CHU) and examined the incidence of stalk rot on 20 maize genotypes (ranging in maturity from 2400 to 3400 CHU). It was found that some *Fusaria* species (such as *F. equiseti, F. moniliforme*) were present year around on maize residues and new seedings. Stalk rot infection was also shown to be related to genotype maturity.

Fusarium fungi are frequently isolated from soils and are commonly associated with maize residues which serve as the main inoculum reservoir for the next planting season (Kommedahl and Windels 1981). The widespread incidence of *Fusaria* fungi is due to their ability to colonize various substrates and to disperse in time and/or space (Burgess 1981). In the present study I examined the mode of colonization of 11 *Fusarium* species and hypothesized that the stalk rot occurrence was related firstly to *Fusarium* fungi that had soilborne mode of dispersal. As we approached grain harvest, airborne species such as *F. graminearum*, and soilborne with air dispersal such as *F. moniliforme*, then replaced the former type. Because of their economic importance, both silage and grain corn were examined.

MATERIALS AND METHODS

The study was conducted during 1991 and 1992 in three growing zones of Eastern Ontario. Cobden with 2400 corn heat unit (CHU) is located 60 miles (100 km) north of Ottawa, Prescott with 2850 CHU is situated 60 miles south of Ottawa, and Ottawa with 2700 CHU. Farmers prepared each study site according to their current tillage practice: conventional plowing in the fall at Cobden, flailed stalk and plowing in the fall followed by discing the following spring in Ottawa, and minimum tillage using disc implant in the spring at Prescott.

Twenty-two genotypes of maize representing three maturity groups: early (8 genotypes); medium (6 genotypes) and late (8 genotypes) were selected for different degree of susceptibility to *Fusarium* (Darrah 1985, Lamkey 1987, Bob Hamilton pers. comm.) (table 2.1 in chapter 2). Inbred CI31A and DE811 were not planted at Cobden, since this is beyond their maturity limit.

A split-plot experimental design with 4 replicates was used where genotype group (inbred, hybrid or synthetic) was randomized to the main plot units and genotype-lines were randomized to the sub-plots units. Each sub-plot consisted of a single row (8 m long by 90 cm wide) of approximately 50 plants (24,000 plants/acre) with the front and the end two plants of each row discarded (to avoid a border effect). Data on the occurrence of each *Fusarium* species was obtained at silage (mid-September) by dissecting 5 plants (i.e., every third one) and at grain harvest (late-October) by dissection of 10 plants. Samples of rotted tissue were aseptically collected with forceps, dipped in 75% ethanol, put in plastic sterile capsules [Sarstedt (1.5 ml, 39x10 mm), West Germany], and stored in a freezer at -20°C until processed for *Fusarium* spp. identification.

Isolation and Cultural Techniques

The stored samples were initially plated on pentachloronitrobenzene (PCNB) medium (selective for *Fusarium* species) amended with streptomycin sulfate (1.0 g/l) (Nash and Snyder 1962, Nelson *et al.* 1983) in 15 cm diameter petri dishes at 25°C for 5-7 days under natural daylight. Cultures growing from the sampled pieces were transferred to a synthetic nutrient agar (SNA) medium in 6 cm diameter petri dishes, on which a piece of sterile filter paper (1 cm^2 triangular) had been deposited (Nirenberg 1976). SNA culture plates were incubated under 4 fluorescent tubes (Sylvania Cool White (F40 CW)) with one black light tube (Sylvania Black Lite Blue (F40 BLB)) in the center, at 25°C under 12:12 L:D cycle for at least 14 days. Cultures that developed on SNA were examined using a Zeiss phase contrast microscope (model D-7082, Axioskop) and identifications were made with the aid of an illustrated morphological manual of Fusaria species (Nelson *et al.* 1983) and a computer-based synoptic key developed by K. Seifert (pers. comm.).

Once identified, the *Fusarium* species were grouped according to three basic modes of dispersion (Burgess 1981). Type I are soilborne species which disperse passively by wind or rain and are commonly associated with roots, lower and aerial plant parts, where in the latter part they remain inactive until suitable conditions for germination and colonization occur. Type II are airborne and disperse passively and/or actively by ascospores. They colonize aerial plant parts. Finally, type III are <u>soilborne with air dispersal mechanisms</u> and are colonizers of aerial plant parts. **Statistical analyses** using SAS-GLM procedure (SAS version 6.03, SAS 1988) were performed after the percentage transformation using arcsin square root of the percent (Little and Hills 1976) to satisfy the assumption of the general linear model. Comparision of the means within varieties and between treatments was only carried out if the treatment F-ratio was significant.

RESULTS AND DISCUSSION

Fusarium complex

Mycological incidence of each *Fusarium* species in **1991** is summarized in table 4.1. Stalk rot fungi were isolated in 30% of the samples at silage and 54% at grain harvest. The species recovered included *F. moniliforme* (Sheldom), *F. graminearum* Schwabe, two species of most concern in breeding improvement programs, and 9 additional species. Significant differences between the incidence of fungi were detected to reveal the major species complex for each location (F=17.6, p<0.01 for Cobden; F=20.2, p<0.01 for Ottawa; F=16.5, p<0.01 for Prescott). The major species isolated was *F. avenaceum* (Fr.) Sacc. at Cobden, *F. moniliforme* at Ottawa, and *F. oxysporum* Schlecht. at Prescott at both harvest periods. Concomitantly, during both harvests, three soil species were repeatedly isolated from the stalk: *F. avenaceum*, *F. equiseti* and *F. oxysporum*.

In **1992**, the *Fusarium* stalk rot averaged 50% at silage and 45% at grain harvest (Table 4.2). The lower incidence of stalk rot at grain harvest may be explained by the below normal temperature in October. The three soil species and *F. moniliforme* accounted for more than 65% of the species complex at silage, and 50% at grain time. Significant differences were again detected between the incidence of fungal species to reveal the species complex for each location (F=8.4, p<0.01 for Cobden; F=30.6, p<0.01 for Ottawa; F=5.1, p<0.01 for Prescott). At silage, *F. avenaceum* was the main species isolated in Cobden, *F. moniliforme* in Ottawa, and *F. equiseti* in Prescott, whereas at grain harvest, *F. sporotrichioides* was

Table 4.1 Percentage of *Fusarium* species isolated from maize stalks in 3 locations (CHU) at silage and grain harvest in 1991 (± standard error).

	Location					
Fusarium Species	Cobden (2639)		Ottawa (3254)		Prescott (3464)	
	silage[a]	grain[b]	silage	grain	silage	grain
F. avenaceum	34.5	24.8	23.1	1.0	8.6	1.3
		(3.0)		(0.3)		(0.5)
F. culmorum	0	6.4	7.7	1.5	0.0	1.9
		(0.9)		(0.3)		(0.7)
F. equiseti	6.9	9.6	23.1	7.5	3.8	18.6
		(1.7)		(1.2)		(1.3)
F. graminearum	3.5	5.7	0	1.5	1.0	5.8
		(1.4)		(0.4)		(2.2)
F. moniliforme	15.5	18.5	30.7	37.1	1.9	17.9
		(1.5)		(2.7)		(1.7)
F. oxysporum	20.8	14.6	7.7	14.4	29.5	25.0
		(1.8)		(2.4)		(2.0)
F. solani	0	0.6	0	9.3	11.5	9.0
		(0.3)		(1.1)		(1.8)
F. poae	0	0.6	0	2.1	8.6	3.2
		(0.3)		(0.3)		(0.9)
F. sambucinum	6.9	7.0	0	11.9	21.0	3.2
		(1.2)		(1.1)		(1.4)
F. sporotrichioides	12.0	12.1	7.7	9.3	13.3	5.7
		(2.5)		(0.9)		(2.0)
F. subglutinans	0	0	0	4.1	1.0	7.7
				(0.4)		(2.3)
Fusarium mixture[c]	8.0	13.2	10.1	9.3	13.3	3.2
Total *Fusarium* (n)	24	163	13	196	52	176
Total plated samples(N)	74	268	53	376	160	346

[a] harvest in mid-September

[b] harvest in late-October

[c] multiple *Fusarium* species

Table 4.2 Percentage of *Fusarium* species isolated from maize stalks in 3 locations (CHU) at silage and grain harvest in 1992 (± standard error).

Fusarium Species	Location					
	Cobden (2311)		Ottawa (2647)		Prescott (2978)	
	silage[a]	grain[b]	silage	grain	silage	grain
F. avenaceum	24.3	14.1	3.2	5.5	14.6	5.0
	(3.6)	(5.1)	(2.2)	(1.4)	(5.0)	(3.0)
F. chlamydosporum	4.9	9.1	0.3	6.9	6.3	5.6
	(2.5)	(3.7)	(0.1)	(1.3)	(1.7)	(2.2)
F. crookelens	0.5	5.1	0.5	3.0	0.4	0.0
	(0.2)	(2.9)	(0.5)	(0.8)	(1.7)	(2.2)
F. equiseti	23.8	10.1	18.7	11.2	31.0	16.4
	(3.9)	(4.3)	(3.0)	(2.0)	(2.9)	(2.3)
F. graminearum	0.5	1.0	0.2	1.1	2.5	0.1
	(0.3)	(0.8)	(0.1)	(0.2)	(1.6)	(0.1)
F. moniliforme	3.4	1.0	47.0	38.2	5.2	9.5
	(1.7)	(0.6)	(6.2)	(4.4)	(1.9)	(4.8)
F. oxysporum	18.4	17.2	13.1	3.5	15.3	20.9
	(2.4)	(5.9)	(2.1)	(0.3)	(3.8)	(6.1)
F. solani	2.9	4.0	6.3	1.2	9.4	9.9
	(0.9)	(2.3)	(1.7)	(0.6)	(2.6)	(3.1)
F. poae	1.0	1.0	0.2	0.7	0.2	0.5
	(0.2)	(0.8)	(0.2)	(0.2)	(0.2)	(0.5)
F. sambucinum	15.0	5.1	2.4	2.3	5.4	5.7
	(3.9)	(3.1)	(0.2)	(0.2)	(2.5)	(2.2)
F. sporotrichioides	4.4	22.2	6.6	22.3	7.7	17.4
	(1.2)	(5.1)	(1.7)	(1.0)	(2.0)	(2.2)
F. subglutinans	0	11.1	2.7	1.6	2.1	6.2
		(5.1)	(1.2)	(0.4)	(1.1)	(2.9)
Fusarium mixture[c]	1.5	21.2	7.3	4.8	6.9	27.8
Total *Fusarium* (n)	206	121	439	474	306	522
Total plated samples(N)	476	583	709	858	696	891

[a] harvest in mid-September
[b] harvest in late-October
[c] multiple *Fusarium* species

favoured at Cobden, *F. moniliforme* at Ottawa and *F. oxysporum* in Prescott.

Fusarium moniliforme varied between 2-37% in 1991 and 1.0-47% in 1992 depending on the localities; *F. graminearum* accounted for less than 6% in 1991 and 1% in 1992, and *F. sporotrichioides* increased from 12% in 1991 to 22% in 1992. The former species arise during warm and dry growing seasons (Messiaen and Cassini 1981) such as 1991 growing season, the second during warm and wet fall conditions (Sutton 1982) more like 1991 than 1992 season, while the third species prevailed in cool and wet fall (Kommedahl and Windels 1981) such as 1992. In both years, *F. graminearum* incidence was low and unpredictable. In Eastern Ontario, the particular climatic conditions and the reduced length of favorable colonization conditions in the fall shortened: 1) the period of stalk susceptibility (i.e., between filling and grain translocation), 2) diminished the fungi exposure to favourable climatic conditions in September which would affect the colonization period, and 3) shortened the period of time between penetration of a host by a pathogen and the first appearance of disease symptoms on the host under optimum colonization conditions.

Fusarium mode of dispersal

To determine the method of stalk colonization, the stalk rot incidence was analyzed as a function of its modes of dispersal (Burgess 1981), taking into account the harvest period (Table 4.3). There was a significant difference between the mode of dispersal at each of the locations. Type I species were primarily encountered in Cobden and Prescott (in both years). In Ottawa, no statistical differences were detected at grain harvest between type I and III in 1991 (SNK test) because of the intensive use of crop irrigation system (1991 drought) to ensure artificial maize ear rot and wheat head blight infection with *F. graminearum* and *F. moniliforme* inoculum on the research farm. This could have increased the amount of aerial spore produced and masked type I incidence in our field. The type III species prevailed at Ottawa in 1992.

Table 4.3 Percentage of each *Fusarium* mode of dispersal isolated from corn stalks at 3 locations during silage and grain harvest in 1991 and 1992.

Silage harvest

	Locations								
	Cobden			Ottawa			Prescott		
	I	II	III	I	II	III	I	II	III
1991	69.0	3.5	27.5	61.6	0.0	38.4	83.0	1.0	16.2
	(F=5.18, p<0.05)			(F=10.61, p<0.01)			(F=9.16, p<0.05)		
	n=24			n=13			n=52		
1992	85.9	0.5	12.7	43.2	0.2	56.6	76.3	2.5	21.3
	(F=20.1, p<0.01)			(F=42.2, p<0.01)			(F=17.5, p<0.01)		
	n=206			n=439			n=306		

Grain harvest

	Locations								
	Cobden			Ottawa			Prescott		
	I	II	III	I	II	III	I	II	III
1991	63.6	5.7	30.6	47.7	1.5	50.5	62.8	5.8	31.3
	(F=111.7, p<0.01)			(F=126.3, p<0.01)			(F=53.16, p<0.01)		
	n=163			n=196			n=176		
1992	56.6	1.0	43.3	27.4	1.1	69.0	58.4	0.1	38.7
	(F=31.6, p<0.01)			(F=55.2, p<0.01)			(F=9.07, p<0.05)		
	n=121			n=474			n=522		

note: Primary data are found in Appendix 3.1.

I : Soilborne : *F. avenaceum, culmorum, oxysporum, solani, equiseti, crookelens, sambucinum, poae.*

II : Airborne : *F. graminearum* (group II), *lateritium.*

III: Soilborne with air dispersal : *F. moniliforme, proliferatum, subglutinans, chlamydosporum, sporotrichioides, acuminatum.*

Fusaria species collected at each harvest period showed that soil species (i.e., Type I mode of dispersal) invaded first the stalk tissue prior to silage harvest then their incidence stabilized as grain harvest approached (Table 4.4). The type II and III species, on the other hand, increased as grain harvest approached suggesting the existence of a longer incubation period regulated by climatic conditions or, the necessity for thesespecies to have the pith predigested by type I species so secondary fusaria could infect the tissue.

Fusarium colonization

Requirements for stalk rot infection were investigated at Ottawa and Prescott as a function of genotype-lines, -grouping, and grain-moisture. At Ottawa, some significant differences were observed between the *Fusarium* mode of dispersion regardless of the years, genotype-group, -line and -moisture. Significant differences were detected between genotype-lines at grain harvest in 1991 and at silage in 1992 (Table 4.5). The climatic conditions in October 1992 killed all genotypes (below -2^{0}C) and stalk tissue became contaminated independently of the genotype maturity. Regrouping genotype-lines under their respective mode of pollination showed that the inbred group was generally more susceptible to soil *Fusaria* species (Type I) at grain harvest, whereas hybrid and synthetic lines were more susceptible to type III species (Table 4.6). The grain moisture was significantly related to the *Fusarium* mode of dispersal at grain harvest (Table 4.7), indicating that the stalk of the short season genotype (i.e., most advance in grain drydown) was the first contaminated by soil fusaria species in conjunction with favourable climatic condition exposure ($p<0.05$). This is attributed to the tissue predisposition (i.e., tissue moisture) to sustain fungal invasion. Also, the warmer city microclimate in the fall have prevented *Fusaria* from entering in the resting spore stage to early.

Table 4.4 Mean percentage of *Fusarium* incidence for the mode of dispersal by harvest time interaction (n=3 locations by 2 years).

Mode of dispersal	by	harvest	Mean incidence
Type I species		silage	69.8^{a}
I		grain	52.8^{b}
III		grain	43.9^{bc}
III		silage	28.8^{c}
II		grain	2.5^{d}
II		silage	1.3^{d}

Means do not differ significantly if followed by the same letters using SNK test, P<0.05.

Statistical analysis of the relationship between

Analysis of variance	F value	Probability
Mode	58.81	p<0.01
Harvest	0.003	not significant
Mode by Harvest	4.25	p<0.05

Table 4.5 Analysis of variance of the percentage of *Fusarium* stalk rot as a function of the genotype-lines and the species mode of dispersal at Ottawa in 1991 and 1992.

1991	F value	
	Silage	Grain
Maize Genotype-lines	1.66^{ns}	1.00^{ns}
Fungus Species mode of dispersal	7.58^{**}	94.14^{**}
Lines by mode of dispersal	1.05^{ns}	2.03^{**}
1992		
Maize Genotype-lines	1.41^{ns}	1.47^{ns}
Fungus Species mode of dispersal	77.18^{**}	94.27^{**}
Lines by mode of dispersal	1.42^{ns}	1.02^{**}

Primary data are found in Appendix 4.1
^{ns} not significant
** $p<0.01$

Table 4.6 Mean *Fusarium* incidence for pooled genotypes and individual genotype grouping as a function of the species mode of dispersal at Ottawa.

Ottawa 1991 silage

	Dispersal type		
	I	II	III
Pool genotype**	0.15^{a}	0^{b}	0.08^{ab}
Inbred	0.16^{a}	0^{b}	0.07^{ab}
Hybrid	0.13^{a}	0^{b}	0.11^{a}
Synthetic	only 1 genotype		

Ottawa 1991 grain

	I	II	III
Pool genotype**	0.21^{b}	0.01^{c}	0.29^{a}
Inbred	0.27^{a}	0.01^{c}	0.22^{b}
Hybrid	0.21^{b}	0^{c}	0.40^{a}
Synthetic	0.20^{a}	0.03^{b}	0.28^{a}

Primary data are found in Appendix 4.1

** mean percentage of *Fusarium* for each dispersal type

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Table 4.6 (cont'd).

Ottawa 1992 silage

	Dispersal type I	Dispersal type II	Dispersal type III
Pool genotype[**]	0.16^{b}	0^{c}	0.18^{a}
Inbred	0.19^{a}	0^{b}	0.21^{a}
Hybrid	0.09^{a}	0^{b}	0.13^{a}
Synthetic	0.14^{a}	0^{b}	0.13^{a}

Ottawa 1992 grain

	Dispersal type I	Dispersal type II	Dispersal type III
Pool genotype[**]	0.08^{b}	0^{c}	0.31^{a}
Inbred	0.10^{a}	0.003^{b}	0.34^{a}
Hybrid	0.09^{a}	0^{b}	0.13^{a}
Synthetic	0.08^{b}	0.008^{b}	0.30^{a}

Primary data are found in Appendix 4.1

[**] mean fusarium incidence for each dispersal type

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Table 4.7 Analysis of variance of the mean percentage of *Fusarium* stalk rot for pooled genotypes as a function of the percent moisture and the species mode of dispersal at Ottawa.

Ottawa 1991 silage

Mean *Fusarium* incidence=0.078 F= 1.38^{ns} r^2= 0.157

	df	F	Probability
Rep	2	0.02	ns
Moisture	2	0.20	ns
Type	2	6.18	<0.01
Moisture by type	4	0.09	ns

Moisture index	1	2	3
mean	0.10	0.07	0.07

Ottawa 1991 grain

Mean *Fusarium* incidence=0.173 F= 18.61^{**} r^2= 0.448

Rep	3	0.61	ns
Moisture	2	5.67	<0.01
Type	2	87.03	<0.01
Moisture by type	4	4.16	<0.01

Moisture index	1	2	3
mean	0.20^a	0.19^a	0.14^b

^{ns} not significant

** p<0.01 significance

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, P<0.05.

Table 4.7 (cont'd).

Ottawa 1992 silage

Mean *Fusarium* incidence=0.111 $F = 14.77^{**}$ $r^2 = 0.381$

	df	F	Probability
Rep	3	4.52	<0.01
Moisture	2	1.84	ns
Type	2	66.14	<0.01
Moisture by type	4	1.04	ns

Moisture index	1	2	3
mean	0.12	0.12	0.09

Ottawa 1992 grain

Mean *Fusarium* incidence=0.133 $F = 20.82^{**}$ $r^2 = 0.473$

	df	F	Probability
Rep	3	2.63	<0.05
Moisture	2	6.16	<0.01
Type	2	90.94	<0.01
Moisture by type	4	3.58	<0.01

Moisture index	1	2	3
mean	0.18^{a}	0.12^{b}	0.10^{b}

^{ns} not significant

** p<0.01 significance

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, P<0.05.

In Prescott, some significant differences were observed between the *Fusarium* mode of dispersion regardless of the years, genotype-lines, -groups and grain-moisture. The genotype-lines were significantly different based on their mode of dispersal at grain harvest in 1991 (Table 4.8). The severe drought prior to silage harvest in 1991 and abnormal growing condition in 1992 failed to generate any significant difference. Inbred and synthetic lines were more susceptible to soil fusaria species (Type I) in both years, whereas hybrid susceptibility varied according to years (Table 4.9). The fungal incidence, regardless of the mode of dispersal, was significantly related to the genotype grain moisture in 1991 (Table 4.10) indicating that the early senescing tissue predisposed the pith tissue to infection. In 1992, the *Fusarium* incidence decreased significantly at grain harvest and no significant differences were detected among the 3 moisture groups because most genotypes were immature (i.e., silking or dough physiological stages). The results indicated that the excessive stalk moisture prior to full genotype maturity (grain moisture dry down) delayed the contamination of the pith tissue by the type III species at grain harvest.

Maize genotype growth and the associated *Fusarium* species complex and epidemiology depend directly on environmental conditions which determine epidemic severity. This agrees with Magan and Lacey (1984) which have showed that temperature and moisture interact to influence the growth of all *Fusarium* fungi. In 1991, plant development occurred rapidly and late maturing genotypes attained dent stage prior to killing frost owing to hot and dry weather from planting to harvest; whereas the cooler temperature in 1992 delayed plant emergence, physiological development and prevented genotypes from attaining full maturity. This resulted in an increase in plant breakage prior to and after harvest, without additional fungal contamination.

The common factors that governed genotype-*Fusarium* synchrony are favorable weather which is pre-requisite for the incubation period and genotype predisposition (i.e., the stalk physiological

Table 4.8 **Analysis of variance of the percentage of *Fusarium* stalk rot as a function of the maize genotype-lines and the species mode of dispersal at Prescott in 1991 and 1992.**

1991	F value	
	Silage	Grain
Maize Genotype-lines	0.53^{ns}	2.33^{**}
Fungus Species mode of dispersal	11.79^{**}	116.31^{**}
Lines by mode of dispersal	0.83^{ns}	2.49^{**}

1992		
Maize Genotype-lines	0.85^{ns}	0.56^{ns}
Fungus Species mode of dispersal	35.72^{**}	45.62^{**}
Lines by mode of dispersal	0.66^{ns}	0.91^{**}

Primary data are found in Appendix 4.1

^{ns} not significant

** p<0.01

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, P<0.05.

Table 4.9 Mean *Fusarium* incidence for pooled genotypes and individual genotype grouping as a function of the species mode of dispersal at Prescott.

Prescott 1991 silage

	Dispersal type		
	I	II	III
Inbred[1]	0.21^{a}	0^{b}	0.02^{b}

Prescott 1991 grain

	Dispersal type		
	I	II	III
Pool genotype[**]	0.27^{a}	0.01^{c}	0.10^{b}
Inbred	0.31^{a}	0.01^{b}	0.08^{b}
Hybrid	0.22^{a}	0.01^{b}	0.20^{a}
Synthetic	0.21^{a}	0.01^{c}	0.11^{b}

Primary data are found in Appendix 4.1

[**] mean *Fusarium* incidence for each dispersal type

[1] only Inbred were sampled

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Table 4.9 (cont'd).

Prescott 1992 silage

	Dispersal type		
	I	II	III
Pool genotype**	0.12^{a}	0.02^{b}	0.04^{b}
Inbred	0.13^{a}	0.006^{b}	0.05^{b}
Hybrid	0.13^{a}	0.02^{b}	0.04^{a}
Synthetic	0.11^{a}	0.003^{b}	0.04^{b}

Prescott 1992 grain

	Dispersal type		
	I	II	III
Pool genotype**	0.14^{a}	0^{b}	0.12^{a}
Inbred	0.14^{a}	0^{b}	0.13^{a}
Hybrid	0.17^{a}	0^{b}	0.05^{a}
Synthetic	0.11^{a}	0.003^{b}	0.04^{b}

Primary data are found in Appendix 4.1

** mean fusarium incidence for each dispersal type

Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, $P<0.05$.

Table 4.10 Analysis of variance of the mean percentage of *Fusarium* stalk rot of all maize genotypes as a function of the percent moisture and the species mode of dispersal at Prescott.

Prescott 1991 silage

Mean *Fusarium* incidence=0.133 F= 20.82** r^2= 0.473

	df	F	probability
Rep	3	1.37	ns
Moisture	2	0.68	ns
Type	2	11.90	<0.01
Moisture by type	2	1.10	ns

Moisture index	1	2
mean	0.11	0.07

Prescott 1991 grain

Mean *Fusarium* incidence=0.128 F= 17.57** r^2= 0.459

Rep	3	1.47	ns
Moisture	2	3.51	<0.05
Type	2	68.44	<0.01
Moisture by type	4	1.21	ns

Moisture index	1	2	3
mean	0.15^{a}	0.12^{ab}	0.09^{b}

^{ns} not significant
** p<0.01 significance
Means within a horizontal row do not differ significantly if followed by the same letters using SNK test, P<0.05.

Table 4.10 (cont'd).

Prescott 1992 silage

Mean *Fusarium* incidence=0.060 F= 7.88** r^2= 0.247

	Df	F value	Probability
Rep	3	1.75	ns
Moisture	2	1.98	ns
Type	2	38.51	<0.01
Moisture by type	4	0.28	ns

Moisture index	1	2	3
mean	0.07	0.05	0.06

Prescott 1992 grain

Mean *Fusarium* incidence=0.088 F= 9.12** r^2= 0.275

Rep	3	1.31	ns
Moisture	2	0.49	ns
Type	2	42.39	<0.01
Moisture by type	4	0.20	ns

Moisture index	1	2	3
mean	0.09	0.09	0.08

ns not significant
** p<0.01 significance

condition). From maize pollen shedding/silking stage to silage harvest, *Fusarium* soil species were constantly recovered from the air, leaf collar sheath and they colonized first the wounded tissue. Concurrently, the early senescing stalk tissue, because of accelerated development owing to genotype stress, genotype maturity, tissue predigestion, and warm-humid weather conditions in September, may have conditioned the stalk pith to the type III infectious species (secondary *Fusarium*).

CONCLUSION

Stalk rot due to *Fusarium* is an opportunistic disease (Kommedahl and Windels 1981). In our study, soilborne fungi were always present (*F. equiseti*, *F. oxysporum*, and *F. avenaceum*) and relatively abundant. In Canada, Gordon (1959) isolated the first two species in roughly 90% of the *Fusarium* flora of the soil. Cobden and Prescott sites could have favored the *Fusarium* soilborne type (such as *F. avenaceum*, *F. oxysporum*) because of manure amendment. In Ottawa, the prevalence of soil-air-borne type of fungus (i.e., *F. moniliforme*) may be explained by the close proximity of maize and wheat *Fusarium* experiments, or because the plot is located within the city which allowed extended and warmer fall conditions.

The results show that the soilborne *Fusarium* species (Type I) were the first to contaminate maize tissue (silage vs grain sampling) and where then supplanted by more competitive species of the type II and III at grain harvest. The type I species could have triggered stalk rot development by increasing plant stress and susceptibility, inducing premature pith cell senescence, or rotting and weakening the stalk sufficiently to cause plant breakage prior to harvest. The combination of all these senescencing factors could afterward allow the more pathogenic species to colonize more easily and rapidly tissue already contaminated. This agreed with Rheeder *et al*. (1990) which reported that *F. moniliforme* can suppress the growth of other ear fungi.

In chapter 5, I will determine the rôle played by the European corn borer in *Fusarium* stalk rot occurrence and identify some indicators of European corn borer and *Fusarium* stalk rot resistance. I will demonstrate that *Fusarium* fungi are secondary invader of the stalk tissue.

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Chapter 5.

Rôle played by the European corn borer, *Ostrinia nubilalis* (Hübner), on *Fusarium* stalk rot incidence in maize, *Zea mays* L, in eastern Ontario.

INTRODUCTION

In Ontario, the economic potential of maize (*Zea mays* L), is limited by two major pests: the European corn borer [*Ostrinia nubilalis* (Hübner)] and *Fusarium* fungi. These pests have long been associated with stalk lodging (Hudon *et al.* 1989, McGee 1988) and plant breakage (Chiang and Hodson 1950, Chiang and Wilcoxson 1961, Christensen and Schneider 1948, Foot and Timmins 1983, Koehler and Boewe 1957, OCPA 1961-1993). In eastern Ontario, lodging causes poor harvestability, yield reduction, diminishes grain quality, and increases stalk rot susceptibility (Calvin *et al.* 1988, Chiang and Hodson 1950), Christensen and Wilcoxson 1966, Davidson and Lyon 1979, Godfrey *et al.* 1991).

The advent of conservation tillage, i.e., leaving at least 30% of the surface cover with residues, and unpredictable climatic changes (global warming, increased UV radiation and temperature-tillage interaction) have faovred fungi and insects to adapt rapidly. The European corn borer adjusted quickly to the new environmental conditions (multi-voltinism) and their host diversity on a variety of crop species and weeds rendered them even more threatening to maize (Caffrey and Worthley 1927, Hanec and Laurence 1966, Hudon *et al.* 1989, McLeod *et al.* 1979, Lilly and Harper 1982, Wressel 1952). Simultaneously, *Fusarium* occurrence was associated with the new cultural practices (no-till, minimum tillage, conservation tillage) and maize weather-predisposition (Kommedahl and Windels 1991, Ullstrup 1978, Smith and White 1988, Windels *et al.* 1988). Corn surface residues favoured the multiplication of various soil *Fusarium* fungi and constituted the main inoculum reservoir for the next growing season (Sutton 1982).

The main fungi of concern remained: *Fusarium graminearum, F. moniliforme, F. sporotrichioides*, and *F. culmorum*; but with the abundance of the soil-borne species due to present cultural practices, *F. oxysporum, F. equiseti, and F. avenaceum* (Neish *et al.* 1983), more selection pressure is exerted on the US (Guthrie and Barry 1989) and Canadian maize improvement programs (Hamilton 1994).

Many studies have focused on the corn borer-maize association (Bergvinson 1993, Caffrey and Worthley 1927, Dicke and Guthrie 1988, Guthrie and Barry 1989, Hudon *et al.* 1989, Reid 1989), or the *Fusarium*-maize interaction (Christensen and Wilcoxson 1966, Nelson *et al.* 1983, Reid 1992, Smith and White 1988, Sutton 1982). The interaction of the European corn borer, maize plant and *Fusarium* fungi have not been extensively studied (Chiang and Wilcoxson 1961, Christensen and Schneider 1948, 1950, Foot and Timmins 1983, Hallauer *et al.* 1988, Walden 1978) perhaps because of the numbers of uncontrollable parameters (such as climate, background infection/infestation). The pertinence of this 3 trophic level interaction have been shown by Carruthers *et al.* (1986) and Chiang and Wilcoxson (1961) whereas the corn borer developed more rapidly in maize contaminated by *F. graminearum* or *Colletrotrichum graminicola* possibly due to maceration of maize tissue and preliminary breakdown of carbohydrates by fungal enzymes.

In chapters 2, 3 and 4, genotype maturity, mean August temperature, and genotype grain moisture at harvest were shown to be significantly correlated with pest population and damage severity, as well as *Fusarium* stalk rot incidence. Seasonal temperatures determine the rate of larval development and combined with long daylength instigate production of an additional population in August, thus increasing plant damage. Concurrently, the severity of the *Fusarium* infection depends on climatic conditions (moisture availability), cultural practices (inoculum reservoir), plant predisposition (physiological stage, plant densities, stress) and stalk damage cause by weather, birds, insects or others (McGee 1988, Sutton 1982, Windels *et al.* 1976). Stalk breakage makes harvesting more difficult and time-consuming (Smith and White 1988, Whitney and Mortimore 1957).

The present study is aimed at determining the rôle played by the European corn borer in *Fusarium* stalk rot incidence in maize in eastern Ontario. It is hypothesized that stalks are contaminated by *Fusarium* fungi following maize stalk damage made by the corn borer larva.

MATERIAL AND METHODS

Site, cultivars and pests information: The study was conducted in eastern Ontario at Cobden (2400 Corn Heat Unit), Ottawa (2750 CHU) and Prescott (2850 CHU) in 1991 and 1992. Experiments were conducted on sandy loam and field plots were prepared according to producer practice.

A split-plot experiment with four replicates surrounded by 4 rows of a commercial hybrid (Pickseed 4533) was used at the 3 locations. Genotype-groups constituted the main-plot units (hybrid, inbred, and synthetic) and genotypes the sub-plot units. Each genotype was randomized within genotype-group. Each main-plot measured 178m long by 10m deep with a 2m path between replicates. Each row (8m long) comprised 40 plants to give a plant density of 24,000 plants/acre.

Thirteen inbreds representing three maturity groups: early (short vegetative period: 60-68 days to silking), medium (69-80 days), and late (81+ days) (Darrah 1985); 6 synthetics (65-90 days) and 3 commercial hybrids adapted to eastern Ontario (70-80 days) were evaluated (R.I. Hamilton pers. comm.). Concomitantly, tasselling and silking date were determined when 50% of the genotype-row attained the physiological stage.

In Cobden and Prescott, genotypes were naturally infested by the European corn borer, whereas at Ottawa, genotypes were artificially infested for uniform infestation. At the 3 locations, fungal infection occurred naturally. All statistical analyses were after the arcsin transformation of the square root of the percentage of *Fusarium* stalk rot incidence (Little and Hills 1976), using SAS version 6.03 (SAS, 1988).

Artificial infestation: The corn borer population originated from infested stalk residues collected at Exeter (104 km NE of Ridgetown). Borers were reared in a controlled environment room at the Ridgetown College of Agriculture, Ridgetown, Ontario, according to the technique described by Guthrie (1989). Sixty thousand wax paper discs (1.3 cm diameter) with one egg mass per disc (20-25 eggs) were sent to Ottawa in 3 shipments and each was incubated at 25°C, 80% RH, and 24h of light until the larva reached the black head stage.

The first and last five plants of each row were not infested (border plants). The inner 30 plants received four egg masses per plant (ca. 100 eggs) deposited in two lots of two egg masses in the plant whorl prior to stem elongation and tassel emergence (Gahukar 1975, Guthrie *et al.* 1965). At the end of July, two additional egg masses were attached to the ear sheath (early, mid maturity genotype) or placed in the whorl (late maturity) to mimic August infestation.

European corn borer and Fusarium.

Crop sampling: Maize plants were harvested manually to determine genotype/corn borer/*Fusarium* interaction at silage (mid-September) and grain (mid-October) harvest. From each replicate, seven plants per genotype were dissected at silage (n=28 plants/genotype) and 10 plants at grain harvest (n=40 plants/genotype). Corn borer data comprised the number, length of tunnel and the number of larvae per tunnel; the *Fusarium* incidence was determined for leaf collar sheath, damage-free pith, tunnelled tissue, and insects. All samples collected were kept frozen until processing (-20°C). After harvest, stored tissues were first plated on pentachloronitrobenzene for 5 to 7 days (20-25°C, daylight) for specific *Fusarium* isolation (Nash and Snyder 1962, Nelson *et al.* 1983); then positive samples were transferred on synthetic nutrient agar medium with 0.02% glucose and 0.02% saccharose, at 20-25°C and 12h L:12h D for 14 days (Nelson *et al.* 1983, Nirenberg 1976) to identify the Fusaria species using a computer-based system (K. Seiffert, pers. comm.) and an illustrated manual of *Fusaria* species (Nelson *et al.* 1983).

Weather: Daily maximum-minimum temperatures and precipitation were recorded at each site from the 1st of April to grain harvest in October. Corn heat unit index (CHU) was determined daily using maximum/ minimum air temperature (Major *et al.* 1976) and correlated with *Fusarium* and corn borer occurrence. A CHU ratio was calculated by dividing the total CHU from planting to the first killing frost (-2^{0}C) for each location by the genotype CHU rating. This ratio was then correlated to the number of days to pollen shedding and silking, moisture at silage and grain harvest and *Fusarium* incidence.

RESULTS AND DISCUSSION

Weather and plant development: In 1991, the severe drought observed in Ottawa and Prescott reduced pollen viability and accelerated silk drydown which caused poor synchrony between shedding pollen and ear silking (leading to unfilled ears) whereas in Cobden, drought stress was less severe due to its localization (100 km north of Ottawa). Inversely, in 1992, the poor growing conditions and northerly location of Cobden delayed germination, deferred pollen shedding, silking and pollination; while at Ottawa and Prescott, weather conditions were less detrimental. The killing frosts (-2^{0}C) at Cobden in September blocked prematurely ear filling and increased plant lodging and stalk breakage.

Fusarium incidence: When leaf collar sheath, damage-free pith, corn borer stalk tunnels, and European corn borer larva were plated for *Fusarium* recovery, incidence was highest in the leaf collar sheath and lowest in uninjured stalks (Table 5.1). *Fusarium* incidence in tunnelled stalks (46.4% in 1991; 22.3% in 1992) and corn borer larvae (44.6% in 1991; 16.5% in 1992) were intermediate.

Fusarium equiseti was the main species recovered in the leaf collar sheath and *F. oxysporum* & *F. moniliforme* the principal species recovered in the stalk at silage harvest (Table 5.2).

Table 5.1 Relative frequency (%) of *Fusarium* fungi (all species) from maize pith, leaf axis, borer tunnel and borer larva at grain harvest at Cobden, Ottawa and Prescott in 1991 and 1992[1].

	1991				1992			
	Pith	Leaf Axis	Tunnel	Corn Borer	Pith	Leaf Axis	Tunnel	Corn Borer
Cobden	1.0	81.8	39.2	43.6	0.8	89.3	5.0	4.9
Prescott	2.6	52.2	42.5	47.3	4.5	76.8	39.6	36.9
Ottawa	2.0	59.1	57.5	42.8	10.7	75.0	28.5	29.7
SNK test:	a	c	bc	b	a	c	ab	ab
		F=20.4**				F=23.4**		

Analysis of variance.

	F value	Probability
Contaminated tissu	23.84	p<0.01
Location	0.31	p>0.05
Tissue by location	1.09	p>0.05

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[1] 1576 samples were examined in 1991.
4223 samples were examined in 1992.

** Significant at the 1% level

Same letters for tissues plated within a year do not differ significantly using SNK test, P<0.05.

Table 5.2. Percentage of *Fusarium* species isolated (± s.e.) from maize leaf collar sheath (LCS) and stalk at silage and grain in 1991 and 1992.

	Year							
	1991				1992			
	silage		grain		silage		grain	
Species	LCS	Stalk	LCS	Stalk	LCS	Stalk	LCS	Stalk
F. avenaceum	8.3 ±3.5	8.8 ±1.3	1.5 ±0.3	7.7 ±1.8	10.2 ±2.9	8.9 ±1.9	6.9 ±3.1	5.3 ±0.8
F. culmorum	4.2 ±2.1	0.7 ±0.5	1.5 ±0.8	3.0 ±1.8	0.1 ±0.05	1.1 ±0.5	0	0
F. equiseti	43.9 ±1.8	9.5 ±0.9	23.5 ±1.8	12.0 ±3.2	30.4 ±4.2	17.4 ±3.2	16.5 ±2.5	5.0 ±1.9
F. graminearum	0	1.4 ±0.7	0	5.4 ±2.0	1.4 ±0.6	0.7 ±0.3	1.2 ±0.7	0.3 ±0.2
F. moniliforme	4.2 ±0.9	13.6 ±1.7	20.6 ±4.0	30.2 ±2.1	23.4 ±3.4	31.9 ±4.1	23.9 ±4.1	27.7 ±5.9
F. oxysporum	18.9 ±3.2	23.8 ±2.1	8.8 ±5.3	16.1 ±4.6	12.0 ±2.0	17.4 ±5.8	12.1 ±4.6	19.9 ±4.0
F. sambucinum	0	16.3 ±5.5	7.4 ±5.1	5.1 ±1.6	7.2 ±1.4	3.2 ±0.3	6.8 ±3.0	4.5 ±2.3
F. sporotrichioides	8.3 ±2.9	14.3 ±3.8	13.2 ±2.7	8.8 ±2.8	7.4 ±2.8	9.0 ±2.7	23.4 ±6.4	27.7 ±3.3
F. subglutinans	2.1 ±1.3	2.7 ±0.9	1.5 ±1.0	4.1 ±1.2	2.6 ±1.6	2.8 ±1.1	3.4 ±1.7	6.9 ±2.3
Percent *Fusarium*	48	62	69	28	66	33	61	32
Total number of samples (N)	99	237	99	251	1002	879	1278	1054

At grain harvest, *F. equiseti*, *F. moniliforme* and *F. sporotrichioides* were the major species recovered in the leaf collar sheath and stalk tunnel. The species identified from these tissues indicated that stalk rot occurrence and severity may be influenced by sampling period, tissues and *Fusarium* species particular to each ecotone. The analysis of variance (Table 5.3) indicated that *Fusarium* species, the maize sample period by *Fusarium* species and maize tissues sampled by *Fusarium* species (two-way interaction) were related to the percentage of *Fusarium* stalk rot observe.

Ascospores from maize residues are either air dispersed, soilborne, or soilborne with air dispersal and can, therefore, land on all external plant parts. Leaf collar sheaths containing trapped pollen and water which provide a good fungal growth medium (Christensen and Wilcoxson 1966) were highly colonized by fungi. As the collar sheath is relaxed, contaminated pollen descended passively and invade stressed tissue or stalk damaged by mechanical means, drought, wind or birds. Undamage pith tissue by the corn borer were slightly contaminated due possibly to minute lesion. With the addition of borer multivoltinism (August population), larval population increased significantly and more larvae returned into maize crop, migrating downward on the plant like the July population. This augmented the number of stalk entries in the basal stem, increased the total length of the galleries, created opening for fungi to enter the stalk, and finaly augmented plant breakage and rot susceptibility.

In 1991, because of the above-normal temperature, three or more generations of the European corn borer occurred causing additional stalk damage. Borer digging in the stalk damaged the cells in the vicinity of the tunnels, which combined with accumulation of frass in the galleries favored fungal colonization and invasion. In 1992, fewer generations of the borer occurred and plant damage was reduced correspondingly. Consequently, *Fusarium* stalk rot also diminished. *Fusarium* fungi were recovered in the collar sheath but since the stalk was less damaged and genotypes were late to reach full maturity due to the poor growing weather conditions, *Fusarium* colonization diminished in the galleries

Table 5.3. **Statistical analysis of the relationship between the percentage of stalk rot and the harvest period, tissues sampled, *Fusarium* species, and respective two-way interactions.**

Analysis of variance

Source	df	F value	Probability
Harvest	1	0.26	ns
Tissues sampled	1	0.93	ns
Harvest by tissues	1	1.84	ns
Fusarium species	8	16.33	$p<0.01$
Harvest by *Fusarium*	8	2.30	$p<0.05$
Tissues by *Fusarium*	8	3.39	$p<0.01$
Harvest by tissues by *Fusarium*	8	0.54	ns

resulting from longuer stalk physiological activity later in the season.

Stalk damage & Fusarium association: The genotype-groups (inbred, hybrid and synthetic) were not statistically different among borer parameters within locations nor years (Appendix 2.7), therefore only the inbred genotypes (because of their stability) grown at Ottawa and Prescott (same genotypes) were used to study *Fusarium* stalk rot and corn borer association.

In chapter 4, it was shown that at Ottawa, *F. moniliforme* & *F. oxysporum* and *F. moniliforme* were the primary species recovered in 1991 and 1992, respectively. *Fusarium oxysporum* constituted the principal fungal species in 1991 and 1992 at Prescott. *Fusarium graminearum*, when encountered, was recovered mainly from early maturing inbreds at both locations.

The correlation coefficients of the *Fusarium* stalk rot incidence at Ottawa with plant and borer parameters are given in table 5.4. Stalk rot incidence of all fungal species was negatively correlated to the genotype CHU rating, relative maturity, days to silking, moisture, and borer parameters in 1991 ($p<0.01$) and the silage moisture in 1992. More specifically, *F. moniliforme* stalk rot was negatively correlated with the number of days to attain silking stage in 1991, whereas *F. equiseti* was positively correlated to genotype parameters in 1992 ($p<0.05$) and negatively correlated to insect parameters in 1991 and 1992. The data suggested that probably the latter species first invaded damaged tissues and then was supplanted by other fungi that are better adapted and more competitive such as *F. moniliforme*, or a mix of all species.

In Prescott, the correlation coefficient of the *Fusarium* stalk rot incidence as a function of plant and borer parameters are given in table 5.5. Stalk rot incidence of all species combine was negatively correlated in both years with the genotype CHU, the CHU ratio and the relative maturity, but was not correlated to any insect parameters. *Fusarium oxysporum*, a soil saprophyte species,

Table 5.4 Simple Pearson correlation between plant maturity (CHU), plant development (number of days to silk) and moisture (at silage and grain harvest) on borer damage and *Fusarium* species at Ottawa in 1991 and 1992.

Ottawa

		Maize				European corn borer			
			Number days	Moisture					
Fusarium		CHU	Silk	Silage	Grain	Leaf Feeding	Number Tunnel	Tunnel Length	Number Larvae
Combined spp.	91	-0.54**	-0.82**	-0.62**	-0.50**	NS	0.29*	0.36**	
	92			-0.42**				NS	
moniliforme	91		-0.31**					NS	
	92			NS				NS	
sporotrichioides									
	91			NS				NS	
	92			NS				NS	
equiseti	91						-0.41**	-0.32**	-0.55**
	92	0.45**	0.54**	0.31*	0.51**	NS	-0.38**	-0.38**	-0.32**
avenaceum	91			NS				NS	
	92			NS				NS	
graminearum	91			NS				NS	
	92			NS				NS	

note: Primary data are found in Appendix 5.2

NS not significant
* p<0.05
** p<0.01

Table 5.5 Simple Pearson correlation between plant maturity (CHU), plant development (number of days to silk) and moisture (at silage and grain harvest) on borer damage and *Fusarium* species at Prescott in 1991 and 1992.

Prescott

Fusarium		CHU	Maize Number days Silk	Maize Moisture Silage	Maize Moisture Grain	European corn borer Leaf Feeding	European corn borer Number Tunnel	European corn borer Tunnel Length	European corn borer Number Larvae
Combined spp.	91	-0.42**		NS				NS	
	92	-0.32**			-0.22*			NS	
moniliforme	91			NS				NS	
	92			NS				NS	
sporotrichioides	91						0.46**	0.43**	0.61**
	92	-0.51**		-0.27*	-0.38**			NS	
equiseti	91			NS				NS	
	92					NS	-0.30*	NS	-0.39**
avenaceum	91					0.39**		NS	
	92			NS				NS	
graminearum	91			NS				NS	
	92			NS				NS	

note: Primary data are found in Appendix 5.2

NS not significant
* $p<0.05$
** $p<0.01$

and the principal species recovered was not correlated to any parameters in both years. *Fusarium sporotrichioides*, a cool season fungal species, was positively correlated with the genotype parameters in 1992 and insect parameters in 1991, whereas the soil borne species, *F. equiseti,* was negatively correlated with the insect parameters in 1992 only. The severe drought conditions in 1991 in Prescott associated with early planting and earlier maturation (reduced pollen viability and rapid drydown of silk) diminished ascospore dispersal, colonization of pollen trap in the leaf collar sheath (lack of moisture) and reduced pith invasion.

The multiple regressions of *Fusarium* incidence as a function of plant-physiological and corn borer susceptibility-parameters revealed from several significant models that the cultivar maturity, the tunnel length and the number of tunnel predicted the *Fusarium* stalk rot incidence. The cultivar maturity and the number of tunnels were correlated negatively with stalk rot incidence whereas the tunnel length was positively correlated to rot severity (Table 5.6). Plant pre-disposition and genotype maturity pre-conditioned the stalk to *Fusarium* infection. Small galeries in the stalk did not promote fungi colonization because insufficient growth medium (such as frass, saw (pith) dust accumulation from borer feeding). However, as corn borer increased stalk damages, more frass and digested pith tissue accumulates and plant became under stressed which favor *Fusarium* colonization and infection.

CONCLUSION

In the present chapter, it is shown that undamaged pith tissue was *Fusarium* free, leaf axis (i.e., pollen trapped by the ligule) were highly contaminated by *Fusarium,* corn borer larvae moderate and tunneled pith were consistently infected. The data indicated that at silage, *F. equiseti* was the first invader of plant tissue. This species was developing on pollen in July and then flooded freely the stalk galleries where it spreaded and degenerated pith tissue. Perhaps this species has less specific requirements for development (such as temperature or plant physiological state) before being overgrown by more noxious and competitive species such as *F. moniliforme, F. oxysporum* or others (positively correlated to genotype maturity, number of days to silking and moisture at harvest).

The multiple regression models (Table 5.6) showed that *Fusarium* incidence is negatively correlated with maturity of the genotype but positively correlated to tunnel length. Within a genotype row, plant that were infested by corn borer had *Fusarium* infection and plants that were damage-free had no *Fusarium* recovery. This agreed with Table 5.1 which showed that a much higher incidence of *Fusarium* occurred in the borer tunnels rather than the undamage pith tissue by the borer, and with Table 5.2 which revealed a shift from Type I species (e.g., *F. equiseti*) to Type III, *F. moniliforme*. This suggested that stalk damage has to be present to initiate infection.

Table 5.6 Multiple linear regression of the percentage of *Fusarium* stalk rot occurrence as a function of plant and corn borer susceptibility parameters.

Ottawa - Artificial corn borer infestation and natural *Fusarium* incidence.

Frequency of		Intercept	Parameter(s)	r^2	P
Fusarium spp.	1991=	81.25^{***}	-0.016 CHU***	0.54	0.006
	1992=	94.80^{***}	-0.84 sil**	0.42	0.022
F. equiseti	1991=	28.94^{***}	-0.55 #T** + 0.060 Length*	0.57	0.022
	1992=	-39.13^{*}	+0.018 CHU***	0.45	0.017

note: Primary data are found in Appendix 5.2
Values with *, **, and *** are significant at 5%, 1%, and 0.1%, respectively
CHU = genotype maturity in Corn Heat Unit
#T = number of tunnels
length = mean length of tunneling
sil = silage moisture

Table 5.6 (cont'd).

Prescott - Natural corn borer infestation and *Fusarium* incidence.

Frequency of		Intercept	Parameter(s)	r^2	P
Fusarium spp.	1991=	108.5^{***}	-0.022 CHU*** $-$ 0.058 #T**	0.66	0.007
	1992=	55.48^{**}	-0.0092 CHU**	0.32	0.057
F. moniliforme	1991=	no significant model			
	1992=	8.88	$-.12$ # T**+ 0.026 Length**	0.37	0.12
	or	-11.76	+0.0077 CHU $-$ 0.14 #T**+0.03 Length**	0.49	0.12
F. equiseti	1991=	no significant model			
	1992=	14.44^{**}	-0.033 #T*	0.30	0.066
F. sporotrichioides	91=	-4.93^{ns}	+0.058 #T**	0.46	0.015
	92=	39.42^{***}	-0.0085 CHU***$-$0.088 #T***+0.02 Length***	0.84	0.001

note: Primary data are found in Appendix 5.2
Values with *, **, and *** are significant at 5%, 1%, and 0.1%, respectively
CHU = genotype maturity in Corn Heat Unit
#T = number of tunnels
length = mean length of tunneling
sil = silage moisture

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Chapter 6.

MAIN DISCUSSION AND CONCLUSIONS

This work investigated the effect of the European corn borer, *Ostrinia nubilalis*, and *Fusarium* species on corn production, *Zea mays* L., in 3 ecotones (Cobden 2400 CHU, Ottawa 2700 CHU, Prescott 2850 CHU) of Eastern Ontario by determining: (1) current corn borer biology, environmental factors that influence borer damages, and effect on yield; (2) the *Fusarium* complex, the spatio-temporal occurrence, and the incidence of each *Fusarium* dispersion modes relative to stalk rot; (3) some leading indicators of corn borer and *Fusarium* stalk rot resistance; (5) the type of association that exists between corn borer and *Fusarium* stalk rot in maize; and (6) a model for *Fusarium* stalk rot infection.

It was found that early larval instars do not inflict severe leaf feeding damage to maize plants at any of the 3 locations in Eastern Ontario. Consequently, leaf feeding based on the rating developed by Guthrie *et al*. (1960) was inapropriate for Eastern Canada and inadequate to assess borer 1st generation genotype-resistance because of unpredictable abiotic conditions which alter female egg laying behaviour, neonate establishment, plant development, and host-pest synchrony. Therefore, a rating based on quantitative characters rather than qualitative is proposed.

It was established that 60% of the borer larvae were located in the first 30 cm of stalk from the soil surface in September (regardless of the location), and that this percentage increases as grain harvest approaches in October. Concomitantly, the tunnelling damage in the first 30cm and 60cm of the stalk accounts for 65% and 80% of the total tunnelling, respectively.

Consequently, two evaluation tools were developed that will improve resource allocation: (1) the use of a plant-leaf damage to complement that of Guthrie *et al*. (1960) to standardize genotype rating; and (2) the assessment of the first 60 cm of stalk to evaluate genotype resistance to corn borer.

It was found that grain moisture, an indicator of maturity, was inversely related to plant damage which contribute to plant breakage. Plant breakage incidence is generally low in Ottawa and Prescott because adapted genotypes for these ecotones have reached maturity prior to frost whereas in Cobden (northerly location), breakage increased because of reduce season length, short fall of heat units to complete maturity, lack of adapted genotypes, and early killing frost (i.e., degeneration of pith tissue which reduces standability). Autumn fall winds may increase plant breakage when a stalk is tunnelled by the borer (hollow stalk), but this type of damage remain unpredictable.

Hybrid grain yield was correlated negatively with corn borer damage whereas yield for inbred genotypes was positively correlated with borer susceptibility. Inbreds are pure lines with specific desired traits (such as corn borer resistance, cold tolerance, *Fusarium* resistance, yield, number of leaves, height, etc., etc.). On the other hand, hybrids are developed from lines that possess specific traits (e.g., yield, combining ability, pests or chemical resistance). During the development of a hybrid, yield improvement is the most important character and traits from parental genotypes such as corn borer resistance may be lost. One example is the inbred B73 which had very good combining ability, high yield potential but when crossed with another parent which possesses other desired traits, some of the B73 traits may be lost, and yield or maturity altered.

The environmental stress, as measured by corn heat units ratio, temperature, rainfall, genotype heat unit rating, infection conditions, and insect damage were all related to *Fusarium* epidemic. It was established that *Fusarium* incidence decreases as genotype maturity increases, and on a south→north gradient (mild temperature, longer growing season). It was also determined that saprophytic species abound at any of the three ecotones and were the first to invade stalk tissue in August.

Fusarium stalk rot first occurred on weak plants caused by weather stress, fall climatic conditions, and insect wounding.
Air and leaf surface samples were continually contaminated with

Fusarium spores in July while at that time, stalk tunnels made by corn borer larvae were not infected. This agreed with Mortimore and Ward (1964) who demonstrated that plant phytochemicals and the plant vitality protected the stalk against stalk rot. As grain harvest approaches, stalk rot incidence increases because of stalk predisposition determined earlier in the season [water stress at tasseling (Dodd, 1980; Godfrey *et al.* 1991)], optimum infection conditions and sufficient incubation period in the fall, and plant susceptibility due to reduced stalk physiological activity and senescence of the basal stem cells. Finally, the genotype maturity and the number of tunnels were negatively correlated with *Fusarium* stalk rot incidence, but once the borer had entered the stalk, and proceeded to tunnel (larval establishment), percentage of stalk rot increased significantly.

It was established that overwintering stubble carried *Fusarium moniliforme*, *F. sporotrichioides*, *F. culmorum*, *F. graminearum* and the saprophytic species *F. oxysporum*, *F. avenaceum* and *F. equiseti*. All maize genotypes used were infected by *F. oxysporum*, *F. sporotrichioides* and *F. equiseti*.

It was found that (1) undamaged pith tissue was free of *Fusarium*, (2) leaf ligule, where pollen and spores accumulated, were contaminated since July and constituted the principal on plant reservoir of *Fusarium* inoculum, and (3) the larvae (moderately infected) by their boring into the stalk, makes entries for the fungi to flood in, which then infect pith tissu via frass or pith breakdown colonization in borer tunnel.

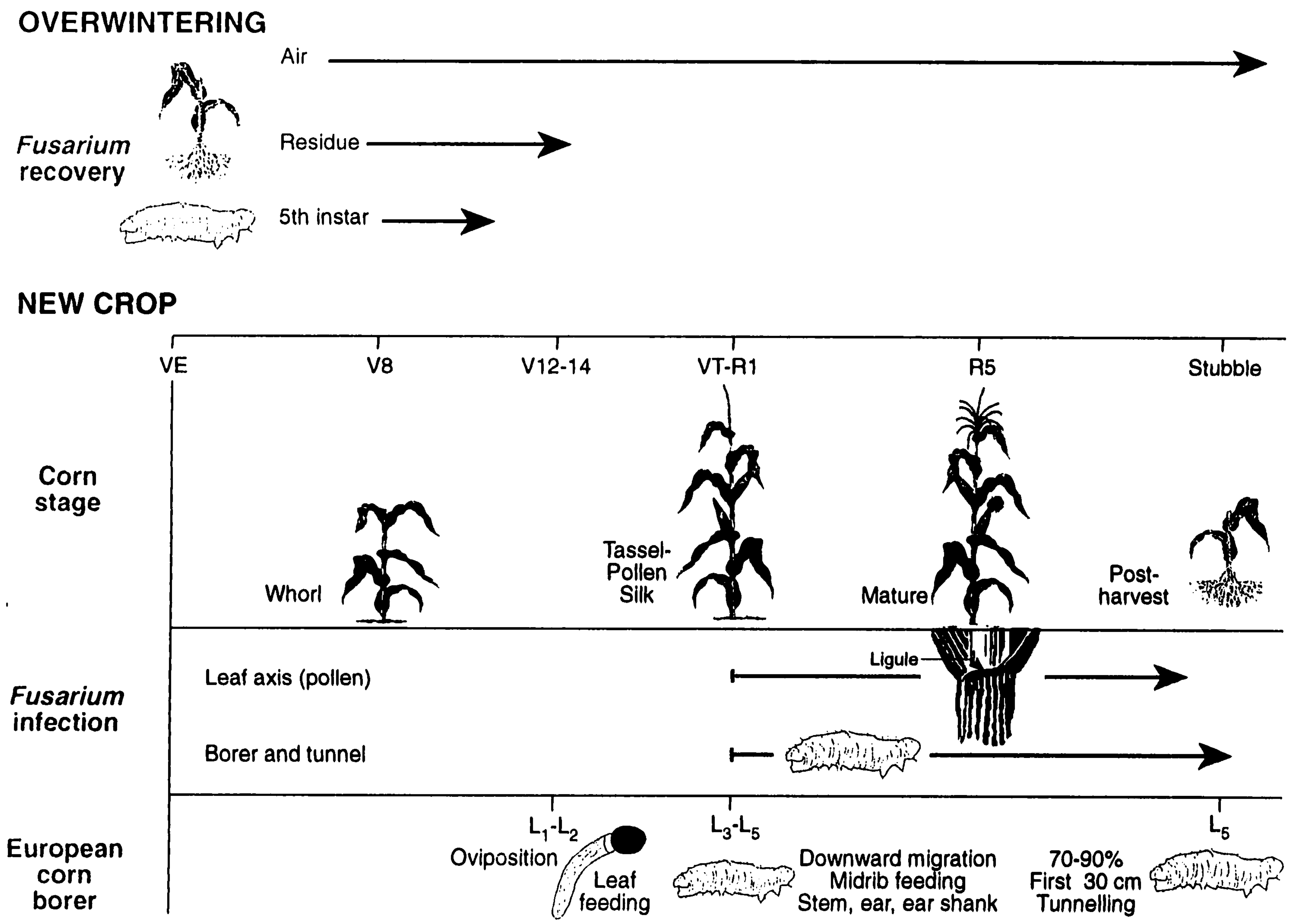
This study showed the importance of host-pests synchrony in term of pests management and breeding improvement objectives. In June, maize is to short (less than 60 cm tall) to attract the corn borer moths for oviposition (Hudon and Leroux 1986) and during borer oviposition in July, plants have passed the 10-14 leaf stage which corresponds to a decrease in plant phytochemical defence (Bergvinson 1993). My results indicated that leaf feeding was not significant nor was correlated with the amount of damage at grain harvest, or corn borer recovery. Instead, I found that mean August temperature was a significant indicator of tunnel damage at grain harvest. Perhaps it is related to the incidence and greater significance of the August population (multivoltine strain), and the return of the corn borer from weeds and other crops into maize. Corn borer drill holes in the stalk as they migrates downward, which create opening for *Fusarium* to enter and invade pith tissues. The effect of climatic and environmental conditions on genotype physiology, corn borer and *Fusarium* ontogeny, as well as the identification of the mechanisms by which maize genotypes may escape borer infestation, and *Fusarium* infection (host-pest synchrony) are mandatory in the further development of elite resistant genotypes.

Finally, among all the insect pests reported in maize, the corn borer is the sole insect in Eastern Ontario that bores holes in the stalk. Some insects may invade the corn borer tunnels, such as the picnic beetle, and transport *Fusarium* inside the stalk (Dowd 1992), others are simply visitors in the galeries, such as ants. Moreover, some insects are external plant feeder, e.g., grass-hopper, armyworm, aphids, corn rootworms, and augment plant stress. Therefore, taking measures to protect the plant from insect injury and extreme climatic variations, would help to control *Fusarium* stalk rot infection.

European corn borer - *Fusarium* - maize model: Leaf ligules were contaminated by *Fusarium* ascospores as soon as the tassel shedded pollen which accumulated in the leaf axis (Figure 6.1). The substrate (pollen) then lodged within the leaf sheath cavity by: 1) loosening of leaf ligule caused by stem expansion, 2) rain stream, or 3) wind action. Plants with physical injury caused by wind and migrating borers (which drill holes into the stalk) permit the inoculum to enter the stalk by: 1) rain splash and then by capillarity, 2) wind dispersal and growth on pollen or insect frass within the tunnel, or 3) by visiting insects. These injuries increase plant stress and initiated cell senescence. The combination of stress, dead cells, insect decays, stalk predisposition, surrounding temperature and moisture triggered stalk rot invasion.

Figure 6.1 Model of *Fusarium* stalk rot occurrence in relation to maize and European corn borer development.

V: refer to maize vegetative stage; E: emergence,
8-14: number of extended leaf; T: tassel;
R: reproductive stage; 1= silking, 5= kernel dent;
L_{1-5}: corn borer larval instar)


OVERWINTERING
Fusarium recovery
Air
Residue
5th instar
NEW CROP
VE
V8
V12-14
VT-R1
R5
Stubble
Corn stage
Whorl
Tassel-Pollen Silk
Mature
Post-harvest
Fusarium infection
Leaf axis (pollen)
Ligule
Borer and tunnel
European corn borer
L_1-L_2
Oviposition
Leaf feeding
L_3-L_5
Downward migration
Midrib feeding
Stem, ear, ear shank
70-90%
First 30 cm
Tunnelling
L_5

Finally, the rot proliferation within the stalk depends on pith nutrient quality, stalk physiological activity (root and lower stem cells senesce first), favourable weather conditions that enhance infection, and borer tunnelling.

Implication of the present study on borer and *Fusarium* management:

The concept of integrated agriculture uses all management tools for corn borer and fungal pest control, concurrently with crop management knowledge (maize sustainable agriculture). In a monoculture such as maize, there are fifteen known factors that may affect plant growth, genetic make-up (due to climatic stress) and pest susceptibility (Francis 1986). In eastern Ontario, no borer parasitoids was recovered and few predators (coccinellids, robber flies, birds, small animals) had an impact on borer dynamics. Insecticides are not currently used on silage or grain corn because of the low crop value. In addition, new conservation strategies do not permit planting within 10m of waterways, due to the chemical restriction (fertilizer and herbicide run off), and cultural practices for soil erosion control. Therefore, these protected area provide a refuge for insect and fungal pests.

Pests establishment and development are achieved through food quality succession (tenderest plant parts), weak, stressed or susceptible plant genotypes, and favourable climatic conditions. Since both pests, the corn borer larva and *Fusarium* spores overwinter in/on maize residues (spatio-temporal distribution), the reduction of overwintering sites may be one of the best management strategies if performed at the right time (re: insect vertical distribution) in conjunction with elite resistant genotypes. The shredding of corn residue during or after harvest could reduce insect pressures and control the fungal inoculum (Sutton 1982).

FUTURE WORK: The present study shows the direct rôle played by the corn borer in *Fusarium* stalk rot incidence. Its leads to the conclusion that reduction of corn borer populations and destruction of overwintering sites could impact <u>only</u> on *Fusarium* stalk rot <u>related</u> to insect damage by reducing plant stress and early senescence of stalk tissue.

Future work should encompass management of corn borer populations by:

1) development of integrated agriculture;
2) recommend that genotypes corn borer resistance be assessed based on new behavioural findings;
3) recommend that genotypes be assessed for *F. equiseti, F. oxysporum* and *F. moniliforme* stalk rot resistance;
4) assessing present adapted genotypes for corn borer susceptibility and determining mechanisms of resistance;
5) finding new sources of resistance to corn borer;
6) develop genotype with resistance to corn borer during August month;
7) maintenance of some stalk activity until harvest;
8) increased stalk rigidity;
9) identification of abiotic parameters of resistance.

These studies are mandatory to establish plant resistance objectives under an actual integrated agriculture ecosystem. The development of multipest resistant genotypes (rootworms, corn borer, armyworm, corn earworm, *Fusarium* fungi) is a high priority but must be achieved through precise monitoring of injurious pest stages in relation to plant development, the identification of susceptible plant stages, and the determination of common resistance factors. A rapid and reliable screening technique taking into account environmental and cultural conditions is important.

Historically, corn borer and *Fusarium* fungi have been subject to various conditions such as monoculture advent, climatic changes and chemical treatment since first reported. In order to develop adequate integrated agricultural management ecosystems, the continual monitoring of pest changes and the identification of the *Fusarium* complex, according to cultural practice changes and climatic variation are necessary. Reducing corn borer wounding would improve lodging resistance, reduce stalk rot infection, and improve yield.

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Appendix 2.1 Geographical and climatic description of the study sites in 1991 and 1992.

	Locations		
	Cobden	Ottawa	Prescott
Latitude (north)	$45^{0}40'$	$45^{0}29'$	$44^{0}43'$
Longitude (west)	$76^{0}45'$	$75^{0}35'$	$75^{0}31'$
Soil type	Manotic sandy loam	Manotic sandy loam	Upland sandy loam
Average Corn Heat Units[•]	2400	2750	2850
Total Corn Heat Units[•]			
1991 season	2639	3132	3371
1992 season	2311	2647	2978

[•] CHU were determined following the method of Major *et al.* (1976).

Appendix 2.2 Vissual description of maize leaf damage rating. (● represent insect damage)

1.0

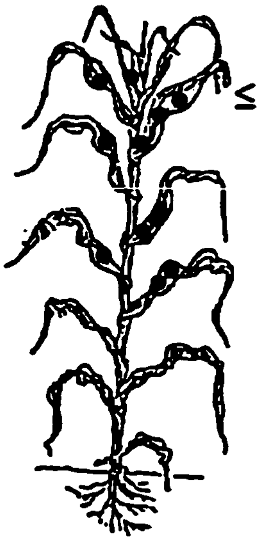
no damage

1.5

≤ 10% defoliation

2.0

≤ 33% defoliation



3.0

≤ 66% defoliation

4.0

> 66% defoliation

Appendix 2.3 Monthly average maximum and minimum air temperature (°C) and total rainfall (mm) at each study site in 1991, and 1992.

1991	COBDEN			OTTAWA			PRESCOTT		
	MAX	MIN	RAIN	MAX	MIN	RAIN	MAX	MIN	RAIN
SEEDING	23 MAY			21 MAY			3 MAY		
MAY	-	-	-	22.0	10.7	58.4	22.7	10.6	83.0
JUNE	25.8	12.0	15.6	26.2	14.6	17.8	26.2	13.7	32.0
JULY	26.8	12.8	86.4	27.9	16.5	86.4	28.5	16.1	42.0
AUGU	26.0	13.1	76.2	26.5	16.9	86.4	27.6	16.7	95.0
SEPT	19.2	5.9	55.9	19.4	9.0	71.1	20.5	11.5	95.0
OCT	14.2	6.0	50.8	17.4	8.9	43.2	16.8	6.8	83.0
frost	21 Sept.			30 Sept.			30 Sept.		

1992	COBDEN			OTTAWA			PRESCOTT		
	MAX	MIN	RAIN	MAX	MIN	RAIN	MAX	MIN	RAIN
SEEDING	25 MAY			21 MAY			5 MAY		
MAY	-	-	-	19.4	7.1	63.6	20.6	7.0	62.9
JUNE	22.7	9.7	25.1	22.6	11.8	52.4	22.9	11.5	61.1
JULY	22.7	11.8	128.0	22.9	13.2	154.8	23.1	13.4	127.9
AUGU	23.8	11.7	98.0	23.1	13.3	109.6	24.3	14.1	67.7
SEPT	20.1	8.2	54.6	19.4	9.7	68.8	20.7	10.0	84.6
OCT	12.1	0.2	61.0	10.7	2.2	45.2	13.5	3.8	48.1
frost	24 Sept.			6 Oct.			24 Sept.		

Appendix 2.4 Inbred genotypes, corn heat unit and seasonal ratio, anthesis, silking, silage and grain moisture, at Cobden, Ottawa and Prescott during the season 1991 and 1992.

CHU: inbred corn heat unit rating given in Darrah (1985) and Hamilton (pers. comm.)
CHU ratio: seasonal CHU/genotype CHU
Anthesis and silking: number of days from emergence

Cobden 1991

Genotype	CHU	CHU ratio	Number of days to Anthesis	Number of days to Silking	Percent Moisture Silage	Percent Moisture Grain
A619	2900	0.91	76	80	.	28.0
B73	3100	0.82	90	96	.	32.0
CG16	2600	1.02	60	67	.	15.0
CK44	2600	1.03	52	55	.	9.0
CO266	2700	1.01	60	62	.	16.0
CM7	2650	1.03	57	59	.	12.0
CO273	2750	0.96	63	67	.	13.0

Cobden 1992

Genotype	CHU	CHU ratio	Number of days to Anthesis	Number of days to Silking	Percent moisture Silage	Percent moisture Grain
A619	2900	0.80	89	92	81.0	91.1
B73	3100	0.72	107	113	80.0	93.1
CG16	2600	0.89	79	85	65.0	58.2
CK44	2600	0.91	73	78	72.1	46.0
CO266	2700	0.87	80	85	67.3	44.0
CM7	2650	0.86	69	73	72.0	42.4
MS72	2800	0.82	80	85	79.8	91.3
CO273	2750	0.84	80	85	79.0	58.0

Appendix 2.4 cont'd.

Ottawa 1991

Genotype	CHU	CHU ratio	Number of days to Anthesis	Silking	Percent Moisture Silage	Grain
A619	2900	1.08	78	85	73.5	38.8
B73	3100	1.01	81	85	75.7	36.6
B86	3200	0.98	85	91	76.2	49.7
CG16	2600	1.20	61	69	69.1	16.5
CK44	2600	1.20	55	63	54.8	11.7
CI31A	3400	0.92	91	97	78.3	64.1
CO266	2700	1.16	69	72	62.3	10.7
CM7	2650	1.18	55	63	58.7	13.1
DE811	2900	1.08	85	91	74.8	45.9
MS72	2800	1.12	78	85	69.4	22.0
OH43	3000	1.04	85	91	74.5	34.1
CO273	2750	1.14	69	74	62.9	11.8

Ottawa 1992

Genotype	CHU	CHU ratio	Number of days to Anthesis	Silking	Percent moisture Silage	Grain
A619	2900	0.91	95	100	82.3	84.8
B73	3100	0.85	100	106	81.0	80.6
B86	3200	0.83	102	106	83.3	77.4
CG16	2600	1.02	74	85	72.3	51.9
CK44	2600	1.02	71	78	65.4	22.3
CI31A	3400	0.78	121	130	79.7	95.9
CO266	2700	0.98	78	85	73.8	25.1
CM7	2650	1.00	71	75	64.6	32.1
DE811	2900	0.91	95	100	80.0	91.6
MS72	2800	0.95	85	95	75.3	55.8
OH43	3000	0.88	94	97	77.8	75.0
CO273	2750	0.96	81	85	73.6	56.1

Appendix 2.4 cont'd.

Prescott 1991

Genotype	CHU	CHU ratio	Number of days to Anthesis	Silking	Percent Moisture Silage	Grain
A619	2900	1.16	70	74	-	15.8
B73	3100	1.09	74	90	62.5	21.1
B86	3200	1.05	80	90	-	10.0
CG16	2600	1.30	67	75	71.1	9.8
CK44	2600	1.30	57	75	52.3	7.8
CI31A	3400	0.99	80	97	-	32.1
CO266	2700	1.25	67	75	69.4	7.4
CM7	2650	1.27	60	75	58.4	11.8
DE811	2900	1.16	80	91	-	28.0
MS72	2800	1.20	75	85	-	9.4
OH43	3000	1.12	70	75	-	11.5
CO273	2750	1.23	70	75	71.6	8.1

Prescott 1992

Genotype	CHU	CHU ratio	Number of days to Anthesis	Silking	Percent moisture Silage	Grain
A619	2900	1.03	94	99	70.8	66.1
B73	3100	0.96	102	106	72.3	73.1
B86	3200	0.93	94	106	65.3	59.3
CG16	2600	1.15	85	94	47.3	37.2
CK44	2600	1.15	77	85	31.1	32.0
CI31A	3400	0.88	103	106	72.8	89.5
CO266	2700	1.10	77	92	53.3	37.0
CM7	2650	1.12	70	92	44.0	30.4
DE811	2900	1.03	100	106	73.9	85.2
MS72	2800	1.06	94	99	62.8	51.3
OH43	3000	0.99	94	99	63.0	55.6
CO273	2750	1.08	85	94	54.0	35.0

Appendix 2.5 **Mean leaf feeding rating (± s.e.) of genotypes grown at each location in 1991 and 1992 (Guthrie *et al.* 1960 scale).**

Inbred	Cobden		Prescott		Ottawa	
	1991	1992	1991	1992	1991	1992
A619	1.04 ±0.02	1.00 ± 0	1.38 ±0.43	1.04 ±0.02	1.11 ±0.03	1.24 ±0.04
B73	1.61 ±0.33	1.19 ±0.13	2.25 ±0.33	2.80 ±0.51	2.17 ±0.46	2.82 ±0.64
B86	--	1.08 ±0.05	1.38 ±0.20	1.74 ±0.18	1.18 ±0.03	2.91 ±0.38
CG16	1.50 ±0.05	1.05 ±0.02	2.83 ±0.22	1.32 ±0.18	1.97 ±0.31	5.00 ±0.39
CK44	1.24 ±0.01	1.10 ±0.04	1.66 ±0.04	1.01 ±0.01	1.13 ±0.07	2.28 ±0.34
CI31A	--	--	1.01 ±0.01	1.65 ±0.01	1.04 ±0.03	1.15 ±0.19
CO266	1.17 ±0.07	1.02 ±0.01	1.04 ±0.06	1.03 ±0.04	1.53 ±0.30	2.23 ±0.17
CM7	1.34 ±0.11	1.30 ±0.05	1.71 ±0.66	1.02 ±0.01	1.24 ±0.01	2.98 ±0.28
DE811	--	--	1.26 ±0.10	1.75 ±0.27	1.28 ±0.07	2.20 ±0.37
MS72	3.07 ±0.21	1.17 ±0.09	1.76 ±0.28	1.87 ±0.27	1.74 ±0.41	4.15 ±0.41
OH43	--	1.08 ±0.03	1.44 ±0.10	1.24 ±0.08	1.12 ±0.06	1.80 ±0.13
CO273	1.41 ±0.40	1.03 ±0.01	1.12 ±0.05	1.11 ±0.02	1.42 ±0.13	1.48 ±0.12
FRH	1.52 ±0.05	1.55 ±0.08	1.26 ±0.10	1.16 ±0.05	2.10 ±0.03	3.61 ±0.29

Appendix 2.5 (cont'd)

	Cobden		Prescott		Ottawa	
	1991	1992	1991	1992	1991	1992
Hybrid						
3925	2.73	1.53	1.30	1.25	1.36	3.51
	±0.47	±0.11	±0.10	±0.04	±0.09	±0.45
4533	2.42	1.14	2.00	2.02	1.76	2.66
	±0.15	±0.03	±0.46	±0.09	±0.01	±0.39
435	2.10	1.36	1.20	1.15	1.22	3.09
	±0.27	±0.11	±0.06	±0.08	±0.07	±0.53
Synthetic						
PRC01	1.35	1.09	1.28	1.18	1.91	1.61
	±0.27	±0.02	±0.30	±0.05	±0.70	±0.10
PRC02	2.05	1.12	1.70	1.22	1.80	2.57
	±0.14	±0.04	±0.34	±0.14	±0.45	±0.46
PRC03	--	--	1.62	1.80	1.97	3.19
			±0.34	±0.22	±0.52	±0.58
PRC04	--	1.11	1.41	1.48	1.78	2.40
		±0.03	±0.16	±0.16	±0.53	±0.17
BS9C0	1.67	1.20	1.20	1.55	1.55	1.77
	±0.32	±0.04	±0.04	±0.09	±0.39	±0.26
BS9C4	1.53	1.19	1.66	1.35	1.26	1.42
	±0.25	±0.01	±0.10	±0.12	±0.20	±0.16

Appendix 2.6 Mean genotypes damages and borer incidence in the basal 30 cm and below the ear, genotype wet weight and grain moisture at grain harvest in October for each locations and years. (t= number of tunnels; cm= tunnel length; 15= number of larva)

Cobden 1991 grain harvest

		AVERAGE							
		< 30 cm			< ear				
Genotype	Rep	t	cm	15	t	cm	15	wet weight	grain moisture
				INBRED					
A619	1	0.40	2.22	0.14	0.50	3.00	0.14	37.4	34.2
A619	2	0.40	2.60	0.03	0.67	4.27	0.17	67.1	26.4
A619	3	1.10	7.40	0.30	1.40	9.70	0.40	39.2	28.1
A619	4	1.40	8.60	0.40	1.90	14.60	0.40	54.4	27.6
B73	1	0.87	4.83	0.77	1.23	7.60	0.93	46.1	29.0
B73	2	1.70	17.10	1.50	2.50	30.90	2.00	42.5	33.4
B73	3	0.60	4.15	0.35	0.85	6.50	0.35	32.4	33.9
B73	4	0.15	0.65	0.05	0.35	2.55	0.10	12.7	40.2
CG16	1	0.13	0.67	0.03	0.13	0.67	0.03	67.9	15.1
CG16	2	0.50	4.80	0.15	0.50	4.80	0.15	86.0	17.3
CG16	3	0.10	0.90	0.05	0.10	0.90	0.05	66.6	11.4
CG16	4	0.50	4.35	0.15	0.60	5.45	0.15	88.1	15.6
CK44	1	0.58	4.38	0.40	0.58	4.38	0.40	49.0	10.4
CK44	2	0.80	5.40	0.50	0.80	5.40	0.50	58.5	8.9
CK44	3	0.70	4.50	0.20	0.70	4.50	0.20	35.1	7.7
CK44	4	0.85	5.75	0.55	0.85	5.75	0.55	58.5	9.1
CO266	1	0.70	4.40	0.30	0.70	4.40	0.30	87.2	18.7
CO266	2	0.35	2.20	0.15	0.45	2.80	0.15	68.3	24.5
CO266	3	0.30	1.95	0.05	0.35	2.05	0.05	47.0	16.1
CO266	4	0.80	5.00	0.30	0.90	5.40	0.35	30.2	18.5
CM7	1	1.40	10.23	0.50	1.43	10.30	0.53	55.2	13.7
CM7	2	1.60	10.55	0.65	1.60	10.55	0.65	59.5	10.9
CM7	3	1.50	10.80	0.40	1.50	10.80	0.40	91.7	8.8
CM7	4	1.60	6.35	0.30	1.65	6.50	0.30	50.7	12.2
CO273	1	0.17	1.10	0.13	0.17	1.10	0.13	74.6	11.8
CO273	2	0.50	2.80	0.40	0.50	2.80	0.40	49.7	13.8
CO273	3	0.90	9.45	0.45	1.05	10.35	0.45	99.0	11.5
CO273	4	0.50	4.50	0.40	0.60	5.00	0.40	50.1	11.9
FRH	1	0.70	4.20	0.25	1.20	7.80	0.50	102.2	10.3
FRH	2	0.90	5.40	0.20	1.70	9.60	0.40	191.6	10.9
FRH	3	2.10	12.20	0.60	2.60	15.00	0.60	205.1	14.9
FRH	4	1.80	9.50	0.70	2.65	20.20	0.80	197.4	16.2
				HYBRID					
PI-3925	1	0.80	5.65	0.30	1.40	10.05	0.35	146.1	17.0
PI-3925	2	1.50	9.75	0.85	2.25	18.10	1.00	206.4	19.7
PI-3925	3	0.85	4.60	0.50	1.45	12.00	0.65	63.1	18.6
PI-3925	4	0.60	3.40	0.40	0.80	4.70	0.50	235.6	20.6
PC-4533	1	0.98	6.75	0.45	1.85	15.40	0.58	99.5	22.9
PC-4533	2	1.50	9.70	0.70	2.10	13.90	0.70	0.0	18.7
PC-4533	3	1.45	12.00	0.85	2.65	23.30	1.35	175.1	15.6
PC-4533	4	0.75	5.20	0.25	1.15	13.35	0.40	123.7	18.5
DK-435	1	1.15	6.35	0.65	1.55	10.25	0.85	142.4	17.1
DK-435	2	0.60	3.55	0.30	1.15	7.05	0.40	129.1	24.5
DK-435	3	0.80	4.25	0.25	0.90	6.90	0.30	110.6	16.6
DK-435	4	1.15	6.80	0.60	1.90	14.80	0.80	205.0	19.3

Cobden 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	Rep	t	cm	15	t	cm	15	weight	moisture
				SYNTHETIC					
SFP-01	1	0.55	4.40	0.25	0.70	6.15	0.30	60.6	17.9
SFP-01	2	1.20	6.30	0.60	1.20	6.30	0.60	89.6	10.1
SFP-01	3	1.70	11.15	0.75	2.35	19.10	1.00	94.8	11.9
SFP-01	4	1.60	12.30	0.90	2.20	16.70	1.00	91.1	12.0
PRC-02	1	1.10	7.40	0.45	1.20	8.40	0.50	58.9	16.9
PRC-02	2	1.30	8.70	0.40	1.50	10.30	0.40	139.4	19.7
PRC-02	3	1.65	13.45	1.00	2.15	17.75	1.15	104.9	24.4
PRC-02	4	0.60	3.35	0.15	0.95	5.25	0.25	70.9	13.2
BS9cy0	1	0.20	1.40	0.10	0.30	2.30	0.10	87.2	31.2
BS9cy0	2	0.35	2.15	0.10	0.60	3.90	0.10	84.2	36.1
BS9cy0	3	0.55	3.90	0.30	0.90	7.85	0.45	105.1	26.0
BS9cy0	4	0.65	3.48	0.33	0.98	7.95	0.38	142.6	29.4
BS9cy5	1	0.20	0.95	0.15	0.45	2.55	0.30	76.9	28.1
BS9cy5	2	0.50	2.70	0.35	0.65	3.95	0.40	161.7	35.3
BS9cy5	3	0.30	2.15	0.10	0.45	6.00	0.10	35.9	29.1
BS9cy5	4	0.40	1.75	0.25	1.00	4.70	0.40	86.4	31.0

cy: cycle

Cobden 1992 grain harvest

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	rep	t	cm	15	t	cm	15	weight	moisture
					INBRED				
A619	1	0.40	0.60	0.00	0.80	1.20	0.00	39.0	95.0
A619	2	0.20	0.60	0.00	0.40	1.00	0.00	19.7	97.1
A619	3	0.00	0.00	0.00	0.00	0.00	0.00	20.9	96.4
A619	4	0.20	0.20	0.00	0.20	0.20	0.00	25.7	94.1
B73	1	0.60	1.80	0.40	0.60	1.80	0.40	0.0	
B73	2	0.20	0.40	0.00	0.20	0.40	0.00	0.0	
B73	3	0.80	3.80	0.20	1.80	6.40	0.20	0.0	
B73	4	0.80	2.40	0.00	1.20	3.40	0.00	0.0	
B86	1	0.00	0.00	0.00	0.20	0.60	0.00	25.8	67.4
B86	2	0.60	5.20	0.00	0.60	5.20	0.00	10.6	92.7
B86	3	0.00	0.00	0.00	0.40	2.20	0.00	0.0	
B86	4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	
CG16	1	1.00	1.80	0.20	1.00	1.80	0.20	43.6	58.2
CG16	2	0.00	0.00	0.00	0.00	0.00	0.00	40.8	63.9
CG16	3	0.40	0.40	0.20	0.60	1.00	0.20	32.4	54.1
CG16	4	0.00	0.00	0.00	0.00	0.00	0.00	58.1	57.4
CK44	1	0.00	0.00	0.00	0.00	0.00	0.00	23.6	43.6
CK44	2	0.00	0.00	0.00	0.00	0.00	0.00	38.2	45.3
CK44	3	0.00	0.00	0.00	0.00	0.00	0.00	32.9	42.7
CK44	4	0.00	0.00	0.00	0.00	0.00	0.00	35.8	50.8
CO266	1	0.40	1.00	0.20	0.60	2.00	0.20	34.3	47.8
CO266	2	0.00	0.00	0.00	0.00	0.00	0.00	32.1	42.9
CO266	3	0.00	0.00	0.00	0.00	0.00	0.00	28.3	32.6
CO266	4	0.00	0.00	0.00	0.20	0.20	0.00	35.0	40.7
CM7	1	0.20	0.60	0.20	0.20	0.60	0.20	69.0	47.5
CM7	2	0.80	2.00	0.20	0.80	2.00	0.20	48.4	39.3
CM7	3	0.00	0.00	0.00	0.00	0.00	0.00	47.8	34.7
CM7	4	1.00	2.00	0.40	1.00	2.00	0.40	54.7	50.9
MS72	1	0.00	0.00	0.00	0.00	0.00	0.00	19.0	91.2
MS72	2	0.60	1.20	0.60	0.60	1.20	0.60	21.1	90.8
MS72	3	0.20	0.40	0.00	0.20	0.40	0.00	22.6	94.3
MS72	4	0.00	0.00	0.00	0.20	0.20	0.00	19.3	92.7
OH43	1	0.00	0.00	0.00	0.40	1.60	0.00	29.2	94.5
OH43	2	0.00	0.00	0.00	0.00	0.00	0.00	28.8	92.8
OH43	3	0.20	0.20	0.00	0.40	0.80	0.00	30.1	89.8
OH43	4	0.00	0.00	0.00	0.00	0.00	0.00	20.0	92.3
CO273	1	0.00	0.00	0.00	0.00	0.00	0.00	23.8	64.0
CO273	2	0.60	2.40	0.40	1.40	6.40	0.40	34.4	61.3
CO273	3	0.40	3.00	0.00	0.80	4.40	0.20	25.6	53.4
CO273	4	0.20	0.40	0.00	0.20	0.40	0.00	24.1	66.7
FRH	1	0.40	3.00	0.00	0.80	5.20	0.00	68.3	63.6
FRH	2	0.20	0.60	0.00	0.40	1.00	0.00	72.6	55.6
FRH	3	0.20	1.00	0.00	0.60	1.80	0.00	77.2	65.1
FRH	4	0.20	1.60	0.00	0.60	5.60	0.20	68.6	52.5

Cobden 1992 grain harvest

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	rep	t	cm	15	t	cm	15	weight	moisture
					HYBRID				
PI-3902	1	0.40	1.60	0.20	1.20	5.20	0.40	100.2	59.8
PI-3902	2	0.20	0.20	0.00	0.40	1.20	0.00	75.4	55.4
PI-3902	3	0.20	0.40	0.00	0.40	0.60	0.00	64.4	57.5
PI-3902	4	0.60	1.40	0.40	1.00	2.40	0.80	69.9	61.8
PI-3925	1	0.20	0.60	0.20	0.40	1.20	0.40	92.4	62.5
PI-3925	2	1.20	5.80	0.40	2.00	9.00	0.40	111.0	57.9
PI-3925	3	0.80	2.20	0.40	2.40	8.00	0.60	92.0	60.7
PI-3925	4	0.60	1.20	0.40	1.00	3.00	0.40	63.6	62.7
PC-4533	1	0.60	2.00	0.40	1.00	5.40	0.40	73.8	69.3
PC-4533	2	0.60	3.00	0.20	1.20	5.60	0.40	89.3	72.9
PC-4533	3	1.00	2.80	0.40	1.40	5.80	0.60	72.2	66.1
PC-4533	4	0.20	0.40	0.00	0.40	2.40	0.20	70.8	73.4
DK-435	1	0.40	0.80	0.00	0.80	1.60	0.00	85.1	70.8
DK-435	2	0.20	0.40	0.20	0.60	1.20	0.20	72.7	67.5
DK-435	3	0.40	1.00	0.00	1.00	2.80	0.00	76.1	67.0
DK-435	4	0.40	0.80	0.00	0.40	0.80	0.00	79.1	70.9
					SYNTHETIC				
SFP-01	1	0.60	2.60	0.20	1.00	6.00	0.40	92.8	41.7
SFP-01	2	0.80	2.40	0.80	1.00	3.40	0.80	80.8	40.8
SFP-01	3	0.20	0.60	0.20	0.40	0.80	0.20	89.9	40.5
SFP-01	4	0.40	1.20	0.40	0.60	1.60	0.40	58.2	47.1
PRC-02	1	0.60	1.60	0.40	0.80	2.00	0.40	102.3	46.9
PRC-02	2	0.40	0.40	0.20	0.40	0.40	0.20	82.9	45.6
PRC-02	3	0.60	2.20	0.40	0.60	2.20	0.40	86.2	41.4
PRC-02	4	0.80	2.00	0.60	1.20	2.80	0.60	61.2	53.5
PRC-04	1	0.20	0.40	0.20	0.60	1.80	0.20	0.0	
PRC-04	2	0.20	0.20	0.00	0.20	0.20	0.00	0.0	
PRC-04	3	0.20	0.20	0.00	0.20	0.20	0.00	0.0	
PRC-04	4	0.20	0.40	0.20	0.60	3.20	0.20	22.5	71.9
BS9cy0	1	0.20	0.40	0.00	0.40	0.60	0.00	41.1	74.3
BS9cy0	2	0.20	0.60	0.20	0.80	3.40	0.20	39.6	92.7
BS9cy0	3	0.40	1.40	0.20	0.60	1.60	0.20	50.6	88.9
BS9cy0	4	0.20	0.40	0.00	0.20	0.40	0.00	37.3	75.5
BS9cy5	1	0.20	0.60	0.20	0.40	1.20	0.20	37.0	89.2
BS9cy5	2	0.20	0.40	0.20	0.20	0.40	0.20	42.7	92.1
BS9cy5	3	0.00	0.00	0.00	0.40	3.40	0.00	0.0	
BS9cy5	4	0.00	0.00	0.00	0.00	0.00	0.00	29.7	95.3

Ottawa 1991 grain harvest

		AVERAGE							
		< 30 cm			< ear			wet	grain
genotype	rep	t	cm	15	t	cm	15	weight	moisture
				INBRED					
A619	1	0.80	4.20	0.60	1.60	8.50	0.80	799.2	42.1
A619	2	0.30	1.60	0.10	0.40	3.10	0.10	949.5	40.8
A619	3	1.40	9.20	0.60	1.60	10.30	0.70	884.3	37.0
A619	4	0.60	3.70	0.30	0.90	6.70	0.40	674.6	39.4
A619	5	1.10	6.90	0.00	1.40	8.70	0.10	433.7	35.6
A619	6	0.90	4.40	0.30	1.00	4.90	0.30	958.5	37.6
A619	7	0.60	3.40	0.00	0.60	3.40	0.00	960.8	38.1
A619	8	1.20	6.50	0.10	1.60	9.00	0.10	353.0	30.6
B73	1	1.70	13.00	0.40	2.40	19.10	0.40	210.3	36.3
B73	2	1.40	8.20	0.30	1.90	13.80	0.40	664.0	35.8
B73	3	1.40	6.30	0.10	1.90	10.10	0.20	353.8	37.5
B732	4	1.80	12.30	0.60	2.20	14.30	0.60	457.9	32.5
B73	5	2.10	13.10	0.20	2.60	16.70	0.20	890.1	35.2
B73	6	0.80	7.30	0.20	1.70	16.00	0.40	304.5	43.7
B73	7	1.40	8.90	0.70	2.10	14.50	0.70	576.4	35.5
B73	8	2.60	16.20	0.30	3.00	19.30	0.40	529.4	34.4
B86	1	0.60	3.40	0.10	0.80	4.40	0.10	213.5	50.8
B86	2	0.00	0.00	0.00	0.00	0.00	0.00	350.1	52.3
B86	3	0.00	0.00	0.00	0.00	0.00	0.00	407.2	50.6
B86	4	0.00	0.00	0.00	0.00	0.00	0.00	384.7	53.7
B86	5	0.50	2.80	0.10	0.90	5.00	0.20	394.6	53.2
B86	6	0.40	2.50	0.00	0.40	2.50	0.00	432.1	42.6
B86	7	1.50	8.00	0.10	1.90	9.80	0.10	280.5	46.2
B86	8	0.40	2.40	0.00	0.40	2.40	0.00	526.8	45.4
CG16	1	1.20	8.90	0.50	2.00	15.10	0.50	722.1	18.0
CG16	2	1.00	9.10	0.30	1.20	11.00	0.30	846.5	15.2
CG16	3	1.20	10.00	0.50	1.70	12.80	1.00	720.0	16.3
CG16	4	1.10	4.10	0.40	1.50	5.80	0.50	565.0	15.8
CG16	5	1.30	7.60	0.30	1.90	10.60	0.50	479.4	13.3
CG16	6	0.90	6.90	0.20	1.10	8.20	0.20	664.6	14.1
CG16	7	1.30	9.00	0.10	1.70	13.80	0.20	657.9	19.3
CG16	8	2.00	13.00	0.30	2.50	16.50	0.40	553.7	21.9
CK44	1	1.30	9.00	0.40	1.30	9.00	0.40	401.1	13.2
CK44	2	2.20	17.00	0.40	2.20	17.00	0.50	292.1	12.4
CK44	3	2.20	11.70	0.50	2.20	11.70	0.60	380.8	9.9
CK44	4	2.00	15.30	0.30	2.00	15.30	0.40	184.1	13.6
CK44	5	1.30	5.20	0.30	1.50	5.50	0.30	419.6	10.7
CK44	6	1.00	9.10	0.30	1.00	9.10	0.40	511.2	9.4
CK44	7	2.20	11.10	0.50	2.20	11.10	0.50	471.4	10.0
CK44	8	1.70	11.00	0.50	1.80	11.50	0.50	367.0	11.3
CI31A	1	1.60	9.50	0.10	2.10	14.30	0.20	34.0	62.1
CI31A	2	1.40	9.60	0.20	1.60	10.70	0.30	323.5	66.3
CI31A	3	0.50	1.10	0.10	1.00	3.20	0.40	357.3	64.7
CI31A	4	1.50	8.60	0.20	2.00	11.70	0.40	257.6	58.9
CI31A	5	1.20	5.70	0.20	1.90	9.50	0.20	149.5	66.4
CI31A	6	0.40	2.30	0.20	0.50	2.70	0.20	255.1	62.4
CI31A	7	1.30	6.50	0.00	1.80	9.50	0.00	225.2	67.5
CI31A	8	1.00	6.80	0.30	1.00	6.80	0.30	172.6	63.1

Ottawa 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear				
genotype	rep	t	cm	15	t	cm	15	wet weight	grain moisture
					INBRED				
CO266	1	2.20	17.60	0.70	2.20	17.60	1.10	275.1	10.5
CO266	2	1.10	9.60	0.20	1.40	10.90	0.30	489.4	8.9
CO266	3	1.80	14.00	0.00	1.80	14.00	0.00	111.4	9.8
CO266	4	2.30	13.30	0.50	2.30	13.30	0.70	230.7	11.1
CO266	5	1.90	14.30	0.20	1.90	14.30	0.40	321.2	11.2
CO266	6	2.30	14.70	0.30	2.30	14.70	0.40	265.5	8.2
CO266	7	2.30	13.90	0.40	2.30	13.90	0.50	269.8	15.3
CO266	8	1.80	10.60	0.50	1.80	10.60	0.50	208.5	9.7
CM7	1	1.70	16.90	0.20	1.70	16.90	0.30	184.5	12.4
CM7	2	0.90	7.30	0.30	1.00	7.60	0.40	835.0	11.2
CM7	3	1.40	11.50	0.40	1.40	11.50	0.40	513.9	10.7
CM7	4	1.60	9.40	0.50	1.60	9.40	0.70	321.0	18.9
CM7	5	1.40	11.60	0.70	1.40	11.60	0.70	570.1	13.1
CM7	6	2.70	18.90	0.20	2.70	18.90	0.20	614.4	10.0
CM7	7	2.20	16.10	0.10	2.20	16.10	0.30	448.1	13.2
CM7	8	2.10	16.00	0.40	2.10	16.00	0.40	302.6	12.9
DE811	1	0.50	3.30	0.10	1.10	9.50	0.10	568.6	45.7
DE811	2	0.40	4.10	0.00	1.00	9.20	0.30	805.9	46.8
DE811	3	0.10	0.30	0.00	0.30	0.80	0.00	961.6	43.0
DE811	4	0.00	0.00	0.00	0.10	1.00	0.00	607.0	52.6
DE811	5	0.10	0.80	0.10	0.50	3.60	0.30	811.9	38.7
DE811	6	0.60	2.70	0.00	0.90	5.20	0.10	711.7	39.0
DE811	7	0.70	3.40	0.00	0.90	4.20	0.10	692.7	45.0
DE811	8	0.10	0.50	0.00	0.10	0.50	0.00	827.5	47.3
MS72	1	0.90	7.70	0.20	1.30	15.60	0.40	639.9	23.6
MS72	2	0.80	4.80	0.10	1.60	9.40	0.10	503.3	18.1
MS72	3	1.10	9.20	0.40	1.20	10.20	0.50	589.2	23.3
MS72	4	1.30	6.90	0.30	1.60	9.40	0.30	436.0	21.1
MS72	5	1.50	9.00	0.30	1.50	9.00	0.30	389.1	26.3
MS72	6	1.10	6.90	0.30	1.20	8.40	0.40	762.7	19.3
MS72	7	1.90	11.10	0.40	2.20	12.40	0.40	698.6	22.4
MS72	8	1.20	6.70	0.40	1.60	9.50	0.40	497.5	21.8
OH43	1	1.00	5.50	0.30	1.20	6.60	0.40	387.7	31.5
OH43	2	0.30	2.30	0.00	0.60	5.00	0.20	483.2	32.1
OH43	3	0.30	1.80	0.00	0.50	3.10	0.20	856.9	39.3
OH43	4	1.20	9.30	0.20	1.70	13.30	0.30	524.1	27.1
OH43	5	0.60	2.20	0.30	0.60	2.20	0.30	634.4	48.7
OH43	6	1.00	5.00	0.10	1.30	6.90	0.10	562.8	37.9
OH43	7	0.80	3.70	0.30	0.80	3.70	0.50	445.6	28.1
OH43	8	1.40	12.50	0.10	1.60	14.80	0.20	433.4	27.8
CO273	1	1.90	14.60	0.90	1.90	14.60	1.10	445.8	12.5
CO273	2	1.60	13.20	0.60	1.60	13.20	0.70	777.7	11.5
CO273	3	1.50	10.50	0.50	1.60	11.50	0.70	613.2	12.3
CO273	4	2.10	13.80	0.60	2.10	13.80	0.70	416.9	12.0
CO273	5	1.40	9.90	0.20	2.10	13.50	0.50	413.6	12.0
CO273	6	2.10	13.20	0.30	2.20	14.00	0.30	706.0	10.8
CO273	7	2.70	15.80	0.60	2.70	15.80	0.60	437.8	11.7
CO273	8	0.80	7.00	0.10	0.80	7.00	0.10	529.7	11.3

Ottawa 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet weight	grain moisture
genotype	rep	t	cm	15	t	cm	15		
					INBRED				
FRH	1	1.80	10.60	0.70	2.90	17.10	0.70	1130.0	15.7
FRH	2	0.80	5.40	0.10	1.70	12.10	0.20	1185.6	13.2
FRH	3	1.80	15.60	1.10	2.10	18.20	1.10	962.1	6.0
FRH	4	0.80	6.30	0.20	1.50	11.90	0.20	1500.7	12.3
FRH	5	0.90	3.80	0.10	2.10	7.60	0.20	1063.5	14.5
FRH	6	1.10	9.10	0.20	1.20	9.40	0.20	1355.3	14.1
FRH	7	1.70	13.60	0.60	2.20	18.30	0.70	1045.7	14.4
FRH	8	1.70	13.70	0.70	1.80	14.70	0.70	1048.6	14.4
					HYBRID				
PI-3925	1	0.30	2.30	0.00	0.90	5.80	0.20	1068.4	17.9
PI-3925	2	1.00	9.80	0.40	1.90	19.80	0.40	942.9	14.6
PI-3925	3	0.40	2.30	0.10	1.60	12.40	0.30	987.0	14.8
PI-3925	4	0.90	4.50	0.40	1.80	10.20	0.50	853.6	20.6
PI-3925	5	0.30	0.70	0.00	0.90	3.90	0.10	1434.3	14.3
PI-3925	6	0.90	6.70	0.50	1.00	7.20	0.50	1395.2	13.2
PI-3925	7	1.30	9.70	0.40	2.30	17.50	0.40	1230.8	12.3
PI-3925	8	0.20	1.30	0.00	0.30	2.30	0.00	956.2	19.7
PC-4533	1	0.70	5.90	0.20	1.40	13.00	0.20	735.2	24.6
PC-4533	2	1.50	16.20	0.60	2.00	21.70	0.60	944.5	16.7
PC-4533	3	0.70	6.40	0.10	1.90	18.90	0.30	797.0	16.8
PC-4533	4	1.00	6.10	0.40	1.80	10.60	0.50	721.3	23.2
PC-4533	5	0.60	4.90	0.10	1.60	12.60	0.40	911.0	17.5
PC-4533	6	1.10	8.20	0.50	2.40	20.80	0.90	1198.6	14.3
PC-4533	7	1.20	6.70	0.40	1.90	14.00	0.80	1175.7	14.1
PC-4533	8	0.30	2.10	0.10	0.40	2.40	0.10	1052.4	16.4
DK-435	1	0.50	4.30	0.10	0.90	6.00	0.20	934.0	21.5
DK-435	2	0.90	8.90	0.30	1.60	17.40	0.40	1482.4	14.6
DK-435	3	0.90	6.90	0.20	1.80	18.70	0.50	1142.0	15.2
DK-435	4	0.70	6.10	0.40	1.80	11.70	0.40	980.0	15.7
DK-435	5	0.40	3.10	0.00	0.90	5.90	0.00	1248.6	16.1
DK-435	6	0.70	6.80	0.10	1.30	11.00	0.20	1374.3	13.5
DK-435	7	0.70	3.60	0.40	1.80	12.40	1.00	1129.5	13.0
DK-435	8	0.10	0.80	0.00	0.20	1.30	0.00	1181.2	16.4

Ottawa 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
genotype	rep	t	cm	15	t	cm	15	weight	moisture
				SYNTHETIC					
SFP-01	1	1.00	5.80	0.40	1.20	7.20	0.40	510.0	14.7
SFP-01	3	2.10	16.70	0.20	2.60	21.20	0.40	365.3	17.6
SFP-01	4	1.40	8.10	0.40	2.10	14.90	0.50	529.6	18.9
SFP-01	5	1.50	11.80	0.20	2.20	17.60	0.60	473.1	13.7
SFP-01	6	0.60	4.10	0.00	1.20	7.90	0.20	648.5	12.7
SFP-01	7	1.30	9.50	0.00	1.50	11.00	0.10	397.3	15.5
SFP-01	8	1.10	9.10	0.10	1.20	9.60	0.10	632.5	16.4
PRC-02	1	1.10	9.50	0.20	1.70	15.50	0.30	558.2	18.1
PRC-02	2	1.70	14.80	0.40	2.10	17.40	0.40	655.4	20.5
PRC-02	3	0.70	5.20	0.20	1.20	8.40	0.30	523.1	18.4
PRC-02	4	0.70	3.00	0.10	1.20	5.40	0.20	345.9	22.6
PRC-02	5	0.70	2.40	0.00	1.00	3.40	0.10	516.1	19.3
PRC-02	6	1.60	9.20	0.10	1.80	10.50	0.10	595.8	19.4
PRC-02	7	0.80	7.10	0.00	0.90	8.30	0.00	678.6	18.3
PRC-02	8	0.50	2.90	0.20	0.60	3.40	0.30	368.6	21.6
PRC-03	1	0.70	6.70	0.10	1.50	12.90	0.30	769.7	38.8
PRC-03	2	1.20	10.70	0.30	2.30	20.00	0.40	791.7	37.4
PRC-03	3	0.80	4.80	0.10	1.50	10.70	0.30	532.9	38.3
PRC-03	4	0.00	0.00	0.00	0.00	0.00	0.00	308.6	42.9
PRC-03	5	1.20	9.10	0.30	1.60	11.00	0.30	326.6	47.9
PRC-03	6	0.50	3.30	0.20	1.10	5.30	0.20	465.3	39.4
PRC-03	7	0.30	1.60	0.10	0.70	4.50	0.10	829.2	40.3
PRC-03	8	0.60	3.90	0.20	1.20	8.60	0.20	356.0	43.3
PRC-04	1	1.30	11.20	0.10	2.20	17.30	0.20	642.1	42.5
PRC-04	2	0.70	5.00	0.00	1.30	8.60	0.10	736.5	43.7
PRC-04	3	1.10	7.60	0.20	1.60	14.40	0.30	719.2	39.4
PRC-04	4	0.50	5.20	0.10	1.40	13.20	0.30	863.0	33.5
PRC-04	5	0.30	1.30	0.00	1.10	5.70	0.00	614.4	40.5
PRC-04	6	0.90	4.80	0.20	1.40	7.10	0.30	795.7	39.6
PRC-04	7	0.80	4.60	0.00	1.00	5.60	0.00	1063.9	37.6
PRC-04	8	0.70	4.00	0.00	0.80	4.50	0.00	684.5	40.0
BS9cy0	1	1.00	7.30	0.20	1.30	9.20	0.30	1228.6	30.7
BS9cy0	2	0.80	4.20	0.20	1.20	6.80	0.20	1416.8	42.2
BS9cy0	3	0.50	3.60	0.10	0.70	4.70	0.20	1287.7	35.9
BS9cy0	4	0.80	2.70	0.60	1.30	4.40	0.80	1099.0	35.9
BS9cy0	5	0.30	1.40	0.00	0.70	3.70	0.00	1242.7	37.6
BS9cy0	6	0.40	1.80	0.10	0.80	4.20	0.10	1328.1	31.1
BS9cy0	7	0.90	7.00	0.00	1.00	7.50	0.00	1160.3	32.6
BS9cy0	8	0.40	2.10	0.00	0.50	2.90	0.00	920.8	38.2
BS9cy5	1	0.40	3.00	0.10	0.60	4.30	0.10	731.8	38.9
BS9cy5	2	0.60	3.50	0.20	0.60	3.50	0.20	1083.6	39.3
BS9cy5	3	0.70	5.20	0.00	0.80	5.70	0.00	1287.1	31.5
BS9cy5	4	0.10	0.20	0.00	0.20	0.80	0.00	802.0	35.7
BS9cy5	5	0.20	1.00	0.20	2.90	0.30	0.50	887.2	35.0
BS9cy5	6	0.20	1.20	0.00	0.30	1.40	0.00	1392.3	35.6
BS9cy5	7	0.50	4.60	0.20	0.70	5.60	0.20	986.0	28.8
BS9cy5	8	0.40	1.80	0.10	0.60	3.10	0.10	1140.6	34.9

Ottawa 1992 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	rep	t	cm	15	t	cm	15	weight	moisture
				INBRED					
A619	1	0.80	1.20	0.00	2.00	5.60	0.20	93.1	71.78
A619	2	0.20	2.00	0.20	0.60	5.60	0.20	172.0	87.32
A619	3	0.20	0.60	0.00	1.00	2.00	0.00	142.5	88.33
A619	4	0.40	0.80	0.00	0.40	0.80	0.00	134.6	86.46
B73	1	3.00	7.20	1.60	4.80	14.20	2.20	35.3	70.63
B73	2	1.80	5.20	0.80	3.00	8.40	0.80	14.5	75.77
B73	3	1.60	4.00	0.60	2.40	6.20	0.60	89.6	84.84
B73	4	0.40	1.40	0.20	0.60	1.60	0.20	91.9	89.72
B86	1	1.00	3.00	0.20	2.80	8.00	0.80	39.5	43.64
B86	2	0.60	3.00	0.00	1.80	8.20	0.20	32.5	62.77
B86	3	1.20	5.20	0.80	2.00	7.60	1.00	102.2	86.67
B86	4	0.20	0.40	0.00	0.20	0.40	0.00	37.3	41.41
CG16	1	3.80	11.00	1.80	5.00	18.40	2.00	59.6	31.62
CG16	2	3.20	11.20	1.60	4.60	18.60	1.80	50.9	37.92
CG16	3	2.00	7.00	0.40	3.60	14.80	0.80	37.3	38.28
CG16	4	1.60	7.20	0.80	2.00	8.00	1.00	72.7	37.96
CK44	1	3.20	6.20	1.60	5.20	18.00	2.40	48.4	20.96
CK44	2	3.60	9.80	1.40	5.20	18.20	1.40	34.4	21.02
CK44	3	1.40	2.60	0.20	3.20	7.60	0.40	36.3	23.12
CK44	4	1.60	3.40	0.20	2.20	5.40	0.40	34.0	24.38
CI31A	1	0.20	0.20	0.20	0.20	0.20	0.20	0.0	0.00
CI31A	2	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00
CI31A	3	1.00	2.60	0.00	1.00	2.60	0.00	0.0	0.00
CI31A	4	0.00	0.00	0.00	0.00	0.00	0.00	0.0	0.00
CO266	1	3.00	6.00	0.60	3.40	8.80	0.80	34.9	28.21
CO266	2	2.40	7.00	1.00	3.60	12.40	1.20	52.7	22.88
CO266	3	1.80	6.60	0.60	2.60	10.60	0.60	21.4	22.08
CO266	4	1.20	2.60	0.00	2.00	4.20	0.00	59.4	24.59
CM7	1	2.00	4.80	0.80	3.60	9.80	1.20	68.2	22.73
CM7	2	1.20	2.80	0.00	1.80	3.60	0.00	67.5	34.65
CM7	3	0.40	2.00	0.20	1.20	6.80	0.20	27.5	40.26
CM7	4	0.00	0.00	0.00	0.00	0.40	0.00	57.9	30.84
DE811	1	0.40	1.40	0.40	1.40	3.00	0.80	47.7	72.92
DE811	2	0.00	0.00	0.00	1.40	3.60	0.20	19.6	86.06
DE811	3	0.20	1.00	0.00	0.20	1.00	0.00	89.0	93.82
DE811	4	0.00	0.00	0.00	0.00	0.00	0.00	24.4	86.97
MS72	1	1.60	3.40	1.00	3.40	7.60	1.60	27.3	40.68
MS72	2	1.00	2.40	0.40	2.00	5.80	0.40	34.7	56.78
MS72	3	0.40	2.00	0.00	0.80	4.20	0.00	45.4	53.27
MS72	4	0.20	1.00	0.00	0.60	2.60	0.00	26.0	55.31
OH43	1	1.20	2.60	0.60	1.80	4.20	0.80	27.0	74.77
OH43	2	2.00	5.60	0.60	2.60	10.60	0.80	48.4	60.69
OH43	3	0.80	2.20	0.60	1.40	5.60	1.00	100.2	88.78
OH43	4	0.20	0.20	0.00	0.20	0.20	0.00	87.8	76.26
CO273	1	3.00	6.80	1.20	5.60	13.80	1.60	39.4	41.72
CO273	2	0.80	1.80	0.60	1.40	4.60	0.80	72.7	79.38
CO273	3	2.40	8.80	0.60	3.20	16.40	1.00	33.2	61.65
CO273	4	2.00	6.80	0.40	2.60	8.60	0.40	50.5	41.94

Ottawa 1992 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	rep	t	cm	15	t	cm	15	weight	moisture
					INBRED				
FRH	1	1.40	2.60	1.40	2.80	9.80	2.20	112.8	34.00
FRH	2	0.60	1.60	0.00	1.60	5.80	0.60	85.6	40.12
FRH	3	0.40	2.20	0.00	0.80	5.60	0.20	104.7	32.86
FRH	4	0.20	1.00	0.00	0.60	2.60	0.20	103.9	31.25
					HYBRID				
PI-3902	1	0.09	0.40	0.02	0.38	1.18	0.07	153.9	43.77
PI-3902	2	0.80	4.00	0.00	1.60	6.00	0.20	134.5	31.79
PI-3902	3	0.00	0.00	0.00	0.80	2.40	0.00	161.5	33.93
PI-3902	4	0.20	0.60	0.00	0.60	2.60	0.20	95.7	38.55
PI-3925	1	0.20	0.96	0.02	0.31	1.84	0.02	155.1	49.02
PI-3925	2	0.60	1.40	0.20	1.80	5.60	0.20	119.2	38.50
PI-3925	3	0.60	1.80	0.40	0.80	3.80	0.40	133.3	40.00
PI-3925	4	0.00	0.00	0.00	0.20	0.20	0.00	69.7	45.15
PC-4533	1	0.11	0.51	0.04	0.36	1.80	0.11	144.4	48.65
PC-4533	2	2.00	7.60	0.80	3.60	13.80	1.20	110.8	36.88
PC-4533	3	1.00	3.00	0.00	1.80	6.00	0.20	99.4	43.20
PC-4533	4	0.40	2.00	0.00	1.60	5.80	0.40	81.2	38.40
DK-435	1	0.13	0.27	0.00	0.36	0.80	0.00	144.2	53.11
DK-435	2	1.00	4.60	0.80	2.00	10.40	1.00	157.1	43.42
DK-435	3	0.20	0.40	0.00	0.40	4.20	0.00	139.1	42.04
DK-435	4	0.60	1.80	0.00	1.20	6.80	0.00	97.6	41.82
					SYNTHETIC				
SFP-01	1	1.10	3.90	0.60	2.90	12.00	0.80	74.4	40.76
SFP-01	2	1.00	2.40	0.40	3.40	10.60	1.00	78.1	27.03
SFP-01	3	0.80	1.80	0.20	2.00	6.60	0.40	66.3	36.23
SFP-01	4	0.80	2.60	0.20	1.60	5.80	0.60	64.3	28.04
PRC-02	1	0.40	0.70	0.10	1.00	2.10	0.10	128.8	48.09
PRC-02	2	1.00	2.40	0.40	3.00	10.80	1.00	65.8	30.05
PRC-02	3	1.00	5.40	0.00	2.00	10.00	0.40	63.3	42.66
PRC-02	4	1.60	3.80	0.60	2.80	9.80	1.20	74.7	29.56
PRC-03	1	1.20	5.00	0.50	3.40	12.00	0.90	109.5	77.42
PRC-03	2	0.60	1.60	0.20	2.20	8.80	0.40	134.2	72.57
PRC-03	3	0.00	0.00	0.00	1.20	3.60	0.40	112.0	80.36
PRC-03	4	1.00	4.60	0.60	2.40	7.60	0.60	89.1	79.08
PRC-04	1	0.20	0.70	0.10	2.20	6.80	0.50	77.1	69.62
PRC-04	2	0.20	1.00	0.20	2.00	8.20	0.60	110.9	81.15
PRC-04	3	0.20	0.40	0.20	0.40	2.40	0.20	128.5	70.02
PRC-04	4	0.00	0.00	0.00	0.20	1.00	0.00	111.5	78.84
BS9cy0	1	0.10	0.80	0.00	1.50	6.10	0.30	158.2	69.38
BS9cy0	2	0.40	0.80	0.40	0.60	1.40	0.60	184.6	84.90
BS9cy0	3	0.40	1.20	0.20	0.60	1.60	0.20	193.1	83.06
BS9cy0	4	0.40	0.80	0.40	1.20	4.20	1.00	87.3	82.91
BS9cy5	1	0.30	0.30	0.30	0.70	2.50	0.60	128.7	74.66
BS9cy5	2	0.00	0.00	0.00	0.80	2.40	0.20	162.2	77.82
BS9cy5	4	0.00	0.00	0.00	0.00	0.20	0.00	152.4	81.07

Prescott 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	Rep	t	cm	15	t	cm	15	weight	moisture
					INBRED				
A619	1	0.15	0.90	0.05	0.15	0.90	0.05	79.7	15.0
A619	2	0.38	2.35	0.18	0.38	2.35	0.18	74.2	16.6
A619	3	0.43	2.95	0.18	0.43	2.95	0.18	122.8	15.9
A619	4	0.63	4.68	0.35	0.73	5.43	0.38	83.8	16.0
A619	1	0.38	2.75	0.10	0.43	3.03	0.10	39.8	20.3
B73	2	0.50	2.10	0.23	0.60	2.88	0.30	58.0	22.8
B73	3	0.73	5.00	0.50	0.85	5.40	0.53	51.2	20.7
B73	4	0.78	5.63	0.73	0.93	6.53	0.78	49.6	20.9
B86	1	0.28	1.30	0.05	0.33	1.55	0.05	8.8	16.4
B86	2	0.08	0.50	0.03	0.08	0.50	0.03	32.4	19.9
B86	3	0.10	0.43	0.03	0.20	0.70	0.03	2.1	26.3
B86	4	0.28	1.93	0.10	0.28	1.93	0.10	4.3	20.0
B86	1	0.30	1.38	0.20	0.30	1.38	0.20	61.0	9.3
CG16	2	0.28	1.33	0.13	0.28	1.33	0.13	68.0	9.0
CG16	3	0.25	1.70	0.18	0.33	2.40	0.20	59.3	10.0
CG16	4	0.20	1.38	0.08	0.20	1.38	0.08	46.8	11.1
CK44	1	0.28	1.40	0.23	0.33	1.53	0.23	29.4	8.2
CK44	2	0.43	2.75	0.23	0.50	3.03	0.25	28.7	8.0
CK44	3	0.43	3.35	0.20	0.45	3.43	0.20	31.1	7.0
CK44	4	0.63	4.13	0.25	0.63	4.13	0.25	27.8	8.8
CI31A	1	0.13	0.55	0.10	0.13	0.55	0.10	11.0	31.0
CI31A	2	0.15	0.65	0.08	0.15	0.65	0.08	17.5	37.5
CI31A	3	0.43	2.58	0.25	0.50	2.98	0.28	36.8	41.1
CI31A	4	0.20	1.23	0.20	0.33	1.43	0.28	20.1	37.3
CO266	1	0.30	2.25	0.13	0.30	2.25	0.13	33.9	12.3
CO266	2	1.28	10.93	0.68	1.38	11.70	0.70	44.3	12.4
CO266	3	0.68	4.85	0.28	0.73	5.03	0.33	51.3	11.2
CO266	4	0.53	3.70	0.48	0.58	3.95	0.48	44.8	10.6
CM7	1	0.60	4.03	0.33	0.63	4.08	0.33	47.3	12.3
CM7	2	0.50	3.00	0.18	0.53	3.08	0.18	53.4	11.9
CM7	3	0.73	4.30	0.25	0.78	4.53	0.25	63.1	11.4
CM7	4	0.53	3.38	0.40	0.53	3.38	0.40	46.6	12.2
DE811	1	0.15	0.60	0.10	0.25	1.38	0.10	25.3	26.1
DE811	2	0.10	0.65	0.08	0.10	0.65	0.08	28.5	21.8
DE811	3	0.10	0.30	0.03	0.23	1.38	0.08	97.0	32.0
DE811	4	0.03	0.25	0.00	0.08	0.88	0.03	76.4	33.1
MS72	1	0.25	1.45	0.10	0.25	1.45	0.10	42.4	12.0
MS72	2	0.55	3.78	0.33	0.70	4.85	0.38	39.5	14.0
MS72	3	0.45	3.45	0.23	0.48	3.53	0.23	58.5	12.3
MS72	4	0.45	2.00	0.25	0.48	2.13	0.25	49.9	12.2
OH43	1	0.48	3.05	0.30	0.48	3.05	0.30	58.0	16.7
OH43	2	0.38	2.65	0.18	0.48	3.43	0.18	45.1	19.2
OH43	3	0.43	3.08	0.23	0.45	3.28	0.23	65.3	12.0
OH43	4	0.60	5.55	0.48	0.65	5.88	0.53	47.9	14.0
CO273	1	0.83	5.98	0.48	0.95	6.98	0.48	55.5	8.3
CO273	2	0.55	4.93	0.40	0.55	4.93	0.43	53.4	8.0
CO273	3	0.73	5.08	0.43	0.90	6.93	0.43	68.1	8.5
CO273	4	0.65	5.08	0.33	0.68	5.33	0.33	50.1	7.6

Prescott 1991 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	Rep	t	cm	15	t	cm	15	weight	moisture
					INBRED				
FRH	1	0.40	3.20	0.38	0.58	4.83	0.48	117.4	11.4
FRH	2	0.65	4.50	0.45	0.78	5.53	0.55	95.1	13.5
FRH	3	0.43	2.85	0.18	0.53	3.53	0.23	141.5	14.8
FRH	4	0.73	6.00	0.70	0.80	7.00	0.73	113.5	13.5
					HYBRID				
PI-3925	1	0.40	2.58	0.18	0.50	3.20	0.20	146.4	10.1
PI-3925	2	0.53	4.40	0.30	0.93	10.00	0.40	123.8	9.3
PI-3925	3	0.18	1.55	0.08	0.25	2.43	0.10	119.7	9.8
PI-3925	4	0.35	3.00	0.28	0.45	4.03	0.30	117.0	13.4
PC-4533	1	0.45	3.83	0.13	0.55	4.95	0.20	112.9	11.1
PC-4533	2	0.50	4.20	0.28	0.83	6.90	0.38	142.6	12.8
PC-4533	3	0.38	3.35	0.20	0.43	3.90	0.23	141.5	9.9
PC-4533	4	0.50	4.45	0.30	0.55	4.95	0.30	99.7	11.6
DK-435	1	0.25	1.55	0.13	0.30	1.80	0.15	167.1	11.8
DK-435	2	0.23	2.10	0.13	0.25	2.13	0.13	128.3	13.1
DK-435	3	0.18	1.48	0.08	0.28	2.28	0.10	139.4	11.4
DK-435	4	0.18	0.95	0.03	0.18	0.95	0.03	123.9	11.9
					SYNTHETIC				
SFP-01	1	0.55	3.38	0.13	0.55	3.38	0.13	53.6	9.3
SFP-01	2	0.38	3.25	0.15	0.53	5.20	0.23	68.7	10.6
SFP-01	3	0.28	2.00	0.08	0.55	3.50	0.13	64.4	8.6
SFP-01	4	0.40	3.15	0.15	0.53	3.98	0.18	59.1	10.4
PRC-02	1	0.35	2.73	0.18	0.38	3.10	0.18	66.9	9.2
PRC-02	2	0.48	3.83	0.25	0.50	3.90	0.25	84.5	13.7
PRC-02	3	0.70	4.50	0.23	0.90	5.75	0.25	90.4	30.3
PRC-02	4	0.43	2.98	0.05	0.55	4.08	0.05	67.5	11.1
PRC-03	1	0.40	2.73	0.20	0.58	3.85	0.30	55.7	14.8
PRC-03	2	0.60	5.05	0.35	0.90	7.80	0.43	54.8	14.6
PRC-03	3	0.35	2.10	0.10	0.50	3.23	0.10	112.0	15.7
PRC-03	4	0.25	1.28	0.13	0.33	1.83	0.15	42.2	16.3
PRC-04	1	0.45	2.88	0.20	0.60	3.73	0.25	93.2	23.1
PRC-04	2	0.50	3.25	0.23	0.63	4.95	0.28	104.0	24.8
PRC-04	3	0.40	3.48	0.15	0.63	5.25	0.20	77.6	23.3
PRC-04	4	0.48	2.70	0.15	0.63	4.18	0.18	75.7	25.6
BS9cy0	1	0.33	1.55	0.20	0.38	1.93	0.20	137.5	17.9
BS9cy0	2	0.50	3.20	0.35	0.63	4.08	0.40	136.7	19.2
BS9cy0	3	0.08	0.40	0.03	0.23	1.10	0.08	178.0	19.5
BS9cy0	4	0.15	0.98	0.08	0.20	1.35	0.10	133.0	16.9

Prescott 1992 grain harvest.

		AVERAGE							
		< 30 cm			< ear				
Genotype	Rep	t	cm	15	t	cm	15	wet weight	grain moisture
					INBRED				
A619	1	1.3	5.5	1.0	1.7	6.9	1.1	182.3	62.8
A619	2	2.0	4.8	1.0	2.4	5.8	1.2	106.3	56.5
A619	3	1.6	9.0	1.0	1.6	9.0	1.0	84.1	59.3
A619	4	1.6	9.8	1.2	1.8	10.2	1.4	73.7	58.6
B73	1	2.6	9.2	1.8	3.6	14.6	2.4	178.4	66.3
B73	2	4.8	17.8	2.4	5.2	46.8	3.6	164.9	63.7
B73	3	4.4	17.6	2.6	4.2	22.6	2.8	100.3	60.9
B73	4	7.8	32.6	4.6	5.2	136.8	5.0	107.0	66.7
B86	1	2.1	6.6	1.0	3.6	12.3	1.4	98.3	52.3
B86	2	3.6	17.4	2.2	4.8	24.2	2.4	138.5	47.6
B86	3	3.0	12.4	2.4	3.6	16.8	2.6	105.7	42.3
B86	4	2.6	13.6	1.8	3.4	17.8	1.8	97.5	58.3
CG16	1	1.9	9.2	1.0	2.2	9.7	1.0	49.2	28.0
CG16	2	1.2	3.8	0.0	1.8	5.2	0.2	44.9	32.1
CG16	3	0.6	1.6	0.2	0.6	1.6	0.2	28.5	27.4
CG16	4	2.0	5.2	0.6	2.0	5.2	0.6	37.6	40.4
CG16	1	2.4	9.5	0.7	2.7	10.1	0.7	33.9	18.7
CK44	2	1.4	10.2	0.6	1.6	10.8	0.6	23.8	20.0
CK44	3	1.0	4.2	0.4	1.0	4.2	0.4	15.0	17.7
CK44	4	1.2	5.4	0.2	1.2	5.4	0.2	12.3	13.2
CI31A	1	1.9	5.8	1.5	3.0	9.3	2.2	76.4	90.9
CI31A	2	0.4	2.6	0.4	1.0	5.2	0.6	81.9	81.6
CI31A	3	2.8	11.8	2.0	3.6	13.8	2.6	64.4	90.7
CI31A	4	2.2	13.2	1.2	3.2	15.4	1.8	63.0	86.0
CO266	1	1.7	7.5	0.9	1.8	8.0	0.9	36.7	15.8
CO266	2	2.0	8.2	1.0	2.0	8.2	1.0	40.8	23.5
CO266	3	3.6	11.0	2.0	4.4	14.4	2.4	21.4	26.2
CO266	4	2.2	8.0	1.0	2.8	10.0	1.0	16.0	15.3
CM7	1	1.9	13.2	0.4	2.7	14.9	0.7	33.5	22.5
CM7	2	2.0	7.6	0.0	2.2	8.6	0.0	15.7	17.1
CM7	3	1.0	4.2	0.4	1.0	4.2	0.4	18.8	21.4
CM7	4	1.0	3.6	0.4	1.2	4.0	0.4	20.5	17.3
DE811	1	0.7	3.4	0.2	1.5	6.9	0.3	187.4	74.4
DE811	2	0.4	0.8	0.2	0.4	0.8	0.2	167.9	76.9
DE811	3	1.0	4.0	0.4	1.0	4.0	0.4	94.9	78.7
DE811	4	1.6	5.8	0.4	2.2	7.6	0.6	127.9	74.3
MS72	1	2.3	6.7	1.4	3.0	9.0	1.7	70.5	43.8
MS72	2	3.0	11.0	1.6	3.6	15.0	1.8	57.2	40.3
MS72	3	1.6	5.6	1.2	2.8	11.2	1.2	46.0	48.3
MS72	4	2.0	10.0	1.4	2.4	12.0	1.6	53.5	43.7
OH43	1	2.6	10.9	1.6	3.0	12.4	1.8	61.2	44.6
OH43	2	2.8	11.8	0.6	3.0	12.0	0.6	83.4	45.9
OH43	3	0.6	3.6	0.2	0.8	4.0	0.4	70.9	54.6
OH43	4	1.4	6.8	0.6	1.4	6.8	0.6	60.1	49.1
CO273	1	2.5	11.1	1.2	3.3	13.9	1.6	109.4	22.3
CO273	2	4.4	22.2	3.0	5.4	29.2	3.2	83.4	19.7
CO273	3	3.0	14.6	1.8	3.6	15.8	2.0	50.5	30.3
CO273	4	1.6	4.2	1.2	1.8	4.8	1.2	31.0	23.8

Prescott 1992 grain harvest.

		AVERAGE							
		< 30 cm			< ear			wet	grain
Genotype	Rep	t	cm	15	t	cm	15	weight	moisture
					INBRED				
FRH	1	1.8	6.7	1.0	2.9	12.6	1.3	106.6	36.2
FRH	2	3.0	12.2	1.8	4.0	15.2	1.8	155.6	42.5
FRH	3	3.2	15.2	0.8	4.0	17.4	1.0	97.6	32.8
FRH	4	2.2	12.2	0.8	2.8	15.2	0.8	92.4	35.9
					HYBRID				
PI-3902	1	1.6	8.4	0.7	3.0	13.6	1.0	155.1	23.6
PI-3902	2	1.6	7.3	1.1	2.7	10.3	1.3	138.1	26.2
PI-3902	3	1.6	8.8	0.4	3.4	17.2	0.6	172.9	22.3
PI-3902	4	1.6	9.0	1.2	2.2	12.4	1.4	156.3	25.4
PI-3925	1	2.6	13.5	1.5	3.7	22.3	2.0	180.3	27.7
PI-3925	2	2.2	12.2	1.4	3.5	20.4	1.5	147.1	29.9
PI-3925	3	2.6	11.6	1.8	4.6	21.8	2.4	131.2	28.4
PI-3925	4	1.2	8.6	1.0	3.0	15.6	1.2	161.9	26.5
PC-4533	1	3.2	14.3	2.4	2.9	31.3	2.8	124.7	30.7
PC-4533	2	2.6	14.0	1.6	3.5	19.0	1.9	114.8	33.6
PC-4533	3	3.6	15.6	3.0	4.8	19.8	3.4	127.5	28.1
PC-4533	4	1.2	5.2	1.0	1.4	5.8	1.0	139.5	33.1
DK-4353	1	0.9	3.5	0.6	1.8	7.8	0.6	181.3	31.6
DK-4353	2	1.3	4.8	0.7	2.2	8.3	0.8	164.4	30.9
DK-4353	3	1.4	5.2	0.6	2.0	9.6	0.8	135.9	27.5
DK-4353	4	2.8	14.4	1.4	4.2	20.4	1.8	171.1	30.3
					SYNTHETIC				
SFP-01	1	3.0	13.9	1.7	3.3	14.6	1.8	10.7	37.3
SFP-01	2	2.2	10.2	1.4	2.8	12.2	2.0	8.0	52.9
SFP-01	3	4.4	14.6	3.0	5.0	15.6	3.0	28.2	37.4
SFP-01	4	2.4	14.8	1.2	2.8	15.4	1.2	18.5	11.1
PRC-02	1	2.9	13.6	1.8	4.4	20.3	2.1	21.0	44.0
PRC-02	2	1.0	4.8	0.8	2.0	11.2	0.8	59.3	27.9
PRC-02	3	2.6	18.8	1.2	3.4	24.4	1.2	44.0	35.6
PRC-02	4	2.2	8.0	1.4	2.8	10.0	1.4	46.4	21.3
PRC-03	1	2.6	9.6	1.9	4.5	18.2	2.3	124.5	46.2
PRC-03	2	2.6	14.0	1.6	3.6	21.6	2.2	142.8	48.5
PRC-03	3	1.8	6.4	1.2	2.8	13.0	1.6	113.6	55.7
PRC-03	4	1.2	5.2	1.0	3.4	13.2	1.6	145.4	49.8
PRC-04	1	1.0	3.4	0.7	2.0	8.6	1.1	68.1	62.8
PRC-04	2	2.0	9.2	1.4	2.8	10.8	1.4	98.3	53.5
PRC-04	3	1.2	5.0	1.0	2.6	9.6	1.4	91.1	63.9
PRC-04	4	1.0	6.2	0.2	1.0	6.8	0.2	103.7	53.8
BS9cy0	1	1.7	5.8	0.9	2.6	8.8	1.4	206.7	52.1
BS9cy0	2	1.0	3.0	0.6	1.4	5.0	1.0	262.0	53.6
BS9cy0	3	2.2	7.6	1.0	2.6	8.4	1.0	193.7	61.4
BS9cy0	4	1.0	3.4	0.4	1.8	5.4	0.8	182.6	59.7
BS9cy5	1	1.1	3.4	0.9	1.5	5.4	1.1	163.1	52.8
BS9cy5	2	1.0	4.6	0.8	1.4	5.2	1.2	169.7	65.2
BS9cy5	3	0.8	1.4	0.6	1.0	2.0	0.6	197.7	60.8
BS9cy5	4	0.3	0.8	0.0	0.3	1.2	0.0	114.0	66.5

Appendix 2.7. F values for Barlett test of homogeneity between inbred, hybrid and synthetic.

			Number of tunnel		Length of tunneling		Number of larva	
		df	30cm	ear	30cm	ear	30cm	ear
Cobden	1991	2	0.91^{ns}	3.13^{ns}	0.003^{ns}	1.24^{ns}	1.75^{ns}	2.91^{ns}
	1992	2	5.51^{ns}	3.86^{ns}	2.69^{ns}	0.30^{ns}	0.61^{ns}	0.16^{ns}
Prescott	1991	2	1.94^{ns}	2.94^{ns}	1.48^{ns}	2.39^{ns}	5.61^{ns}	7.13^{*}
	1992	2	1.05^{ns}	0.33^{ns}	0.09^{ns}	0.32^{ns}	1.00^{ns}	0.42^{ns}
Ottawa	1991	2	1.66^{ns}	3.83^{ns}	0.58^{ns}	3.17^{ns}	3.63^{ns}	3.90^{ns}
	1992	2	2.68^{ns}	6.08^{*}	1.34^{ns}	3.98^{ns}	3.83^{ns}	7.86^{*}

* $p < 0.05$

Appendix 3.1 Incidence of all *Fusarium* spp. recovered at three locations in 1991 and 1992 (Data expressed as percent of stalks infected with ± standard error in parenthesis).

		1991			1992		
	GENOTYPE	COBDEN	OTTAWA	PRESCOTT	COBDEN	OTTAWA	PRESCOTT
early*	CG16	66.7 (24.2)	43.3 (16.1)	40.4 (17.0)	19.0 (4.7)	25.7 (8.6)	46.2 (9.2)
	CK44	56.7 (5.3)	46.7 (12.0)	42.2 (6.6)	22.2 (3.8)	38.9 (5.0)	27.1 (6.7)
	CO266	--	43.3 (6.4)	42.2 (9.5)	8.3 (4.5)	28.6 (9.6)	20.6 (6.3)
	CM7	--	42.6 (3.9)	34.4 (9.4)	46.7 (3.3)	75.4 (15.0)	44.4 (4.9)
	CO273	33.3 (8.5)	58.6 (8.3)	34.2 (9.6)	15.4 (2.1)	56.5 (15.0)	42.3 (4.6)
	PRC01	59.4 (18.9)	65.2 (16.2)	40.7 (6.6)	13.3 (3.6)	34.8 (5.8)	32.8 (7.2)
	PRC02	41.7 (11.9)	65.2 (8.9)	60.0 (10.5)	19.4 (7.1)	34.8 (12.9)	40.0 (10.4)
medium	A619	19.2 (8.9)	35.7 (13.5)	64.7 (11.8)	16.7 (8.4)	40.4 (5.0)	32.6 (9.6)
	MS72	--	29.4 (5.7)	30.2 (6.7)	5.6 (2.5)	46.7 (17.3)	34.3 (5.4)
	FRH	--	50.0 (10.7)	22.6 (10.6)	24.2 (6.1)	40.4 (12.9)	29.4 (3.9)
	Pi-3925	80.6 (8.4)	68.0 (7.5)	45.8 (14.6)	16.3 (8.0)	32.4 (9.6)	21.2 (5.6)
	Pc-4533	55.6 (10.4)	51.9 (8.5)	42.9 (4.3)	10.8 (5.1)	22.5 (1.9)	27.5 (7.0)
	Dk-435	35.7 (8.5)	50.0 (9.2)	38.9 (5.3)	20.0 (5.0)	30.6 (5.8)	61.1 (6.4)
	PRC04	--	47.1 (13.1)	14.7 (6.0)	8.8 (4.7)	33.3 (4.0)	28.3 (5.5)

* : genotype maturity

Appendix 3.1 (cont'd).

		1991			1992		
	GENOTYPE	COBDEN	OTTAWA	PRESCOTT	COBDEN	OTTAWA	PRESCOTT
late	B73	15.4 (4.2)	27.9 (7.1)	20.6 (5.8)	23.8 (10.3)	55.4 (12.8)	30.0 (3.3)
	B86	--	57.1 (17.7)	39.1 (8.1)	10.0 (2.5)	44.7 (9.6)	36.8 (9.9)
	CI31A	--	25.0 (5.5)	27.8 (5.3)	--	70.8 (14.1)	12.7 (4.5)
	DE811	--	28.6 (5.1)	37.5 (16.6)	--	41.2 (18.3)	37.0 (5.3)
	OH43	--	56.7 (4.1)	21.7 (7.2)	0.0	32.6 (13.3)	29.7 (8.0)
	PRC03	--	38.5 (3.6)	11.1 (7.2)	--	25.4 (9.6)	36.4 (14.1)
	BS9c0	--	37.9 (6.5)	57.1 (9.4)	35.7 (2.1)	25.0 (9.6)	24.2 (5.3)
	BS9c5	--	40.0 (8.9)	51.9 (8.5)	19.0 (5.8)	31.4 (8.9)	30.4 (3.0)

Appendix 4.1 Mean *Fusarium* mode of incidence for each genotype at Ottawa and Prescott during the season 1991 and 1992 (- not harvested).

Cobden 1991

INBRED	Silage Fusarium Type			Grain Fusarium Type		
	I	II	III	I	II	III
A619	0.04±0.03	0	0.15±0.06	0.05±0.30	0	0.13±0.06
B73	0.13±0.07	0	0.03±0.02	0.17±0.07	0	0.04±0.02
CG16	0.44±0.14	0	0.02±0.01	0.33±0.17	0	0.04±0.02
CK44	0.24±0.14	0.04	0.28±0.07	0.42±0.08	0.04	0.25±0.03
CO273	0.19±0.05	0.03	0.08±0.04	0.39±0.17	0.04	0.26±0.12
HYBRID						
3925	0.41±0.19	0	0.19±0.03	0.66±0.12	0.02	0.13±0.05
4533	0.35±0.11	0.02	0.18±0.04	0.61±0.18	0.01	0.18±0.06
415	0.14±0.06	0	0.21±0.08	0.22±0.09	0.03	0.13±0.05
SYNTHETIC						
PRC01	0.44±0.13	0	0.16±0.04	0.35±0.11	0	0.20±0.08
PRC02	0.25±0.03	0.04	0.17±0.09	0.18±0.12	0	0.08±0.04
BS9c0	0	0	0	0	0	0

Cobden 1992

INBRED	Silage Fusarium Type			Grain Fusarium Type		
	I	II	III	I	II	III
A619	0.08±0.04	0	0	0.07±0.02	0	0.04±0.02
B73	0	0	0	0.02±0.01	0	0.03±0.02
B86	0.04±0.02	0	0	0.12±0.07	0	0.10±0.07
CG16	0.08±0.04	0	0	0.02±0.01	0	0.02±0.01
CK44	0	0	0	0.02±0.01	0	0
CO266	0.21±0.12	0	0	0.06±0.02	0	0.04±0.02
CM7	0.33±0.02	0	0	0.03±0.02	0	0.07±0.03
MS72	0.04±0.02	0	0	0.13±0.09	0	0
OH43	0	0	0	0.05±0.03	0	0
CO273	0.04±0.02	0	0.08±0.04	0	0	0.04±0.02
FRH	0.16±0.08	0	0	0.22±0.06	0	0.38±0.20
HYBRID						
3925	0.14±0.03	0	0.03±0.02	0.08±0.01	0	0.10±0.07
4533	0.15±0.04	0	0	0.08±0.04	0	0
415	0.12±0.08	0	0.03±0.02	0.06±0.03	0	0.07±0.02
SYNTHETIC						
PRC01	0.16±0.01	0	0	0.16±0.07	0	0.03±0.02
PRC02	0.30±0.05	0	0	0.06±0.04	0	0
PRC04	0.17±0.09	0	0	0.02±0.01	0	0.06±0.03
BS9c0	0.04±0.02	0	0	0.02±0.01	0	0
BS9c5	0.06±0.04	0	0.04±0.02	0	0	0.02±0.01

Ottawa 1991

INBRED	Silage Fusarium Type			Grain Fusarium Type		
	I	II	III	I	II	III
A619	0.05±0.07	0	0.50±0.70	0.30±0.20	0	0.20±0.16
B73	0.17±0.05	0	0	0.24±0.18	0	0.19±0.07
B86	0.05±0.15	0	0	0.25±0.20	0	0.25±0.20
CG16	0	0	0	0.20±0.17	0	0.39±0.30
CK44	0.13±0.06	0	0	0.15±0.13	0	0.38±0.22
CI31A	0.22±0.01	0	0	0.15±0.05	0	0.12±0.10
CO266	0	0	0	0.25±0.23	0.03	0.28±0.10
CM7	0.19±0.27	0	0	0.16±0.11	0.02	0.37±0.04
DE811	0.13±0.17	0	0	0.15±0.10	0	0.16±0.11
MS72	-	-	-	0.26±0.05	0.05	0.09±0.07
OH43	0.17±0.23	0	0	0.33±0.15	0	0.27±0.19
CO273	0	0	0	0.19±0.10	0	0.47±0.06
FRH	0.67±0.13	0	0.33±0.11	0.22±0.06	0	0.38±0.20
HYBRID						
3925	0.20±0.14	0	0.09±0.08	0.41±0.30	0	0.27±0.19
4533	0.04±0.07	0	0.09±0.10	0.21±0.10	0	0.38±0.18
415	0.15±0.06	0	0.17±0.05	0.0	0	0.56±0.20
SYNTHETIC						
PRC01	-	-	-	0.37±0.13	0.04	0.29±0.25
PRC02	-	-	-	0.14±0.09	0.04	0.50±0.18
PRC03	only 1 genotype			0.12±0.10	0	0.28±0.07
PRC04	-	-	-	0.13±0.25	0.05	0.20±0.28
BS9c0	-	-	-	0.22±0.15	0	0.26±0.15
BS9c5	-	-	-	0.25±0.20	0.06	0.13±0.14

Ottawa 1992

INBRED	Silage Fusarium Type			Grain Fusarium Type		
	I	II	III	I	II	III
A619	0.19±0.13	0	0.15±0.11	0.05±0.10	0	0.30±0.12
B73	0.14±0.18	0	0.33±0.21	0.20±0.16	0	0.25±0.25
B86	0.15±0.17	0	0.23±0.13	0.05±0.10	0	0.10±0.11
CG16	0.12±0.12	0	0.09±0.07	0.10±0.20	0	0.35±0.10
CK44	0.14±0.11	0	0.35±0.17	0.15±0.30	0	0.55±0.10
CI31A	0.37±0.21	0	0.13±0.09	0	0	0.20±0.28
CO266	0.15±0.10	0	0.26±0.03	0.10±0.11	0	0.25±0.10
CM7	0.17±0.16	0	0.15±0.12	0.15±0.10	0	0.50±0.26
DE811	0.12±0.14	0	0.18±0.16	0.15±0.10	0	0.25±0.30
MS72	0.19±0.12	0	0.27±0.15	0.15±0.10	0	0.35±0.41
OH43	0.29±0.11	0	0.11±0.02	0	0	0.53±0.46
CO273	0.19±0.15	0	0.35±0.15	0.15±0.30	0	0.40±0.28
FRH	0.22±0.07	0	0.17±0.04	0	0.05	0.45±0.30
HYBRID						
3902	0.04±0.04	0	0.12±0.09	0.07±0.11	0	0.33±0.30
3925	0.10±0.07	0	0.14±0.16	0.10±0.07	0	0.14±0.16
4533	0.11±0.12	0	0.07±0.10	0.11±0.12	0	0.07±0.10
415	0.10±0.13	0	0.20±0.17	0.10±0.13	0	0.20±0.17
SYNTHETIC						
PRC01	0.11±0.17	0	0.14±0.05	0.15±0.10	0	0.55±0.19
PRC02	0.11±0.09	0	0.11±0.03	0.10±0.20	0	0.40±0.36
PRC03	0.18±0.18	0	0.20±0.19	0.05±0.10	0	0.20±0.23
PRC04	0.18±0.21	0	0.08±0.06	0.15±0.10	0	0.25±0.10
BS9c0	0.15±0.11	0	0.10±0.11	0	0	0.25±0.19
BS9c5	0.09±0.10	0	0.18±0.14	0.05±0.10	0.05	0.15±0.19

Prescott 1991

INBRED	Silage Fusarium Type I	II	III	Grain Fusarium Type I	II	III
A619	-	-	-	0.49±0.21	0	0.02±0.04
B73	0.10±0.07	0	0	0.10±0.05	0.01	0.03±0.06
B86	-	-	-	0.42±0.16	0	0.02±0.03
CG16	0.19±0.24	0	0	0.46±0.25	0	0.13±0.14
CK44	0.32±0.31	0	0	0.41±0.17	0.04	0.12±0.11
CI31A	-	-	-	0.24±0.13	0	0.02±0.04
CO266	0.13±0.25	0	0.08±0.16	0.42±0.25	0.02	0.12±0.09
CM7	-	-	-	0.19±0.21	0	0.19±0.16
DE811	-	-	-	0.36±0.26	0	0.09±0.10
MS72	-	-	-	0.22±0.06	0.01	0.03±0.05
OH43	-	-	-	0.13±0.011	0	0.10±0.12
CO273	0.32±0.31	0	0	0.23±0.13	0	0.08±0.07
HYBRID						
3925	-	-	-	0.18±0.14	0.03	0.26±0.17
4533	-	-	-	0.24±0.09	0	0.19±0.14
415	-	-	-	0.25±0.06	0	0.17±0.19
SYNTHETIC						
PRC01	-	-	-	0.26±0.02	0	0.20±0.08
PRC02	-	-	-	0.24±0.11	0.03	0.23±0.08
PRC03	-	-	-	0.10±0.12	0	0.03±0.06
PRC04	-	-	-	0.11±0.07	0	0.05±0.06
BS9c0	-	-	-	0.35±0.12	0.03	0.03±0.06

Prescott 1992

INBRED	Silage Fusarium Type			Grain Fusarium Type		
	I	II	III	I	II	III
A619	0.15±0.16	0	0.02±0.03	0.12±0.11	0	0.16±0.14
B73	0.18±0.22	0	0.02±0.03	0.21±0.18	0	0.10±0.03
B86	0.15±0.14	0	0.12±0.15	0.15±0.22	0	0.14±0.13
CG16	0.10±0.06	0.03	0.08±0.16	0.19±0.15	0	0.21±0.16
CK44	0.10±0.04	0	0.09±0.09	0.19±0.15	0	0.06±0.08
CI31A	0.10±0.07	0	0.04±0.04	0.07±0.14	0	0.02±0.04
CO266	0.10±0.12	0	0.02±0.03	0.09±0.07	0	0.09±0.08
CM7	0.24±0.12	0	0.12±0.08	0.08±0.06	0	0.13±0.11
DE811	0.10±0.08	0	0.02±0.03	0.24±0.22	0	0.16±0.14
MS72	0.14±0.15	0	0.04±0.04	0.13±0.12	0	0.19±0.15
OH43	0.10±0.07	0	0.07±0.10	0.12±0.03	0	0.13±0.15
CO273	0.12±0.09	0	0.07±0.08	0.10±0.07	0	0.21±0.07
FRH	0.10±0.13	0	0.03±0.04	0.19±0.18	0	0.07±0.05
HYBRID						
3902	0.17±0.15	0.06	0.08±0.16	0.21±0.19	0	0
3925	0.06±0.04	0	0.02±0.03	0.12±0.08	0	0.09±0.09
4533	0.15±0.07	0	0.02±0.02	0.18±0.12	0	0.04±0.04
415	0.16±0.11	0	0.08±0.16	0.16±0.14	0	0.07±0.08
SYNTHETIC						
PRC01	0.11±0.09	0.02	0.17±0.33	0.13±0.16	0	0.13±0.09
PRC02	0.13±0.03	0	0.02±0.03	0.05±0.06	0	0.22±0.18
PRC03	0.10±0.07	0	0.02±0.03	0.17±0.18	0	0.21±0.26
PRC04	0.08±0.09	0	0.02±0.04	0.23±0.15	0	0.08±0.10
BS9c0	0.13±0.15	0	0	0.11±0.17	0	0.09±0.11
BS9c5	-	-	-	0.08±0.10	0	0.20±0.14

Appendix 5.1 Plant physiological parameters, European corn borer susceptibility and *Fusarium* species incidence (after arcsin square root of the percent) of each inbred genotypes at Ottawa and Prescott during 1991 and 1992 season (CHU: genotype corn heat unit rating, anth: anthesis, silk: silking, sila: silage moisture, grain: grain moisture, leaf feed: corn borer leaf feeding, no tun: number of tunnel, no lar: number of larva, Fus: *Fusarium*, mon: *moniliforme*, spo: *sporotrichioides*, equ: *equiseti*, oxy: *oxysporum*, ave: *avenaceum*, gra: *graminearum*).

Ottawa 1991

Inbred	CHU	CHU RATIO	ANTH	SILK	SILA	GRAIN	LEAF FEED	NO TUN	TUNNEL LENGTH	NO LAR	FUS	MON	SPO	EQU	OXY	AVE	GRA
A619	2900	1.08	78	85	23.45	38.8	1.11	85	500	52	36.7	19.1	10.9	10.9	25.0	0.0	0.0
B 73	3100	1.01	81	85	25.68	36.6	2.17	161	1011	95	31.9	14.8	10.5	7.8	21.2	7.3	0.0
B 86	3200	0.98	85	91	26.16	49.7	1.18	41	201	9	37.1	32.3	0.0	32.3	0.0	0.0	0.0
CG 16	2600	1.20	61	69	19.11	16.5	1.97	170	1070	88	40.7	32.7	11.8	0.0	24.1	11.8	0.0
CK 44	2600	1.20	55	63	4.81	11.7	1.13	179	1153	106	43.1	32.5	8.5	0.0	19.5	8.5	0.0
CI31A	3400	0.92	91	97	22.30	64.1	1.04	135	785	89	30.0	13.4	0.0	0.0	13.4	20.7	0.0
CO266	2700	1.16	69	72	12.25	10.7	1.53	177	1190	99	41.1	18.4	10.5	0.0	21.4	0.0	0.0
CM 7	2650	1.18	55	63	8.65	13.1	1.24	183	1373	68	45.0	25.9	8.3	12.0	14.7	17.0	0.0
DE811	2900	1.08	85	91	24.75	45.9	1.28	38	224	10	32.8	0.0	18.0	12.7	18.0	12.7	0.0
MS72	2800	1.12	78	85	19.38	22.0	1.74	114	700	71	32.2	9.8	9.8	0.0	22.6	9.8	0.0
OH 43	3000	1.04	85	91	24.47	34.1	1.12	93	566	43	28.9	22.8	18.4	12.9	30.0	0.0	0.0
CO273	2750	1.14	69	74	12.94	11.8	1.42	177	1222	113	38.4	34.7	9.8	9.8	17.3	0.0	0.0

Ottawa 1992

Inbred	CHU	CHU RATIO	ANTH	SILK	SILA	GRAIN	LEAF FEED	NO TUN	TUNNEL LENGTH	NO LAR	FUS	MON	SPO	EQU	OXY	AVE	GRA
A619	2900	0.91	95	100	82.3	84.80	1.24	38	98	8	26.2	24.6	16.1	18.1	18.1	0.0	0.0
B 73	3100	0.85	100	106	81.0	80.60	2.82	111	333	27	32.3	33.5	10.6	10.6	18.6	10.6	0.0
B 86	3200	0.83	102	106	83.3	77.40	2.91	48	141	11	16.7	32.8	0.0	12.8	18.2	0.0	0.0
CG 16	2600	1.02	74	85	72.3	51.90	5.00	148	533	36	25.8	21.6	11.7	9.5	15.1	6.8	0.0
CK 44	2600	1.02	71	78	65.4	22.30	2.28	166	493	36	40.5	37.2	13.4	0.0	15.1	0.0	0.0
CI31A	3400	0.78	121	130	79.7	95.90	1.15	25	66	2	32.0	23.1	23.1	28.7	19.8	11.2	0.0
CO266	2700	0.98	78	85	73.8	25.10	2.23	118	380	24	21.6	23.2	13.7	9.6	9.6	9.6	0.0
CM 7	2650	1.00	71	75	64.6	32.10	2.98	73	226	15	43.9	26.8	22.1	10.1	17.9	14.5	0.0
DE811	2900	0.91	95	100	80.0	91.60	2.20	11	28	2	33.0	28.1	0.0	13.7	0.5	19.5	0.0
MS72	2800	0.95	85	95	75.3	55.80	4.15	60	201	22	32.0	31.3	12.7	14.5	0.5	14.5	0.0
OH 43	3000	0.88	94	97	77.8	75.00	1.80	55	135	13	26.3	20.3	11.5	14.2	11.5	16.4	0.0
CO273	2750	0.96	81	85	73.6	56.10	1.48	136	383	35	39.7	35.6	10.1	19.2	10.1	10.1	0.0

Prescott 1991

Inbred	CHU	CHU RATIO	ANTH	SILK	SILA	GRAIN	LEAF FEED	NO TUN	TUNNEL LENGTH	NO LAR	FUS	MON	SPO	EQU	OXY	AVE	GRA
A619	2900	1.16	70	74	-	15.76	1.38	157	1087	75	36.5	14.1	0.0	20.1	39.9	0.0	0.0
B 73	3100	1.09	74	90	62.5	21.07	2.25	177	1165	113	31.8	12.1	0.0	9.8	20.1	0.0	7.0
B 86	3200	1.05	80	90	-	22.98	1.38	72	415	20	38.7	12.0	0.0	21.1	24.7	0.0	0.0
CG 16	2600	1.30	67	75	71.1	9.76	2.83	75	505	40	48.7	14.7	0.0	14.7	28.9	8.3	0.0
CK 44	2600	1.30	57	75	52.3	7.81	1.66	133	863	71	50.8	10.1	0.0	25.7	20.7	0.0	10.1
CI31A	3400	0.99	80	97	-	32.10	1.01	90	500	63	31.8	13.7	0.0	13.7	13.7	0.0	0.0
CO266	2700	1.25	67	75	69.4	7.39	1.04	190	1428	131	41.9	14.2	8.9	22.4	14.2	0.0	6.3
CM 7	2650	1.27	60	75	58.4	11.78	1.71	184	1218	108	35.9	17.9	10.1	17.9	0.0	0.0	0.0
DE811	2900	1.16	80	91	-	27.97	1.26	37	180	20	37.8	14.5	0.0	14.5	30.0	0.0	0.0
MS72	2800	1.20	75	85	-	9.44	1.76	194	1220	103	33.3	15.3	8.7	12.5	22.0	8.7	0.0
OH 43	3000	1.12	70	74	-	11.53	1.44	187	1432	60	27.8	17.2	0.0	0.0	12.0	0.0	0.0
CO273	2750	1.23	70	75	71.6	8.05	1.12	223	1622	145	39.8	7.7	13.3	13.3	24.7	0.0	5.4

Prescott 1992

Inbred	CHU	CHU RATIO	ANTH	SILK	SILA	GRAIN	LEAF FEED	NO TUN	TUNNEL LENGTH	NO LAR	FUS	MON	SPO	EQU	OXY	AVE	GRA
A619'	2900	1.03	94	99	70.8	66.1	1.04	175	792	58	27.6	16.7	15.0	12.9	18.4	7.5	0.0
B 73	3100	0.96	102	106	72.32	73.1	2.8	392	1628	145	30.0	6.8	11.8	6.8	25.6	9.8	0.0
B 86	3200	0.93	94	106	65.29	59.3	1.74	273	1265	110	31.3	13.9	13.9	0.0	21.7	0.0	0.0
CG 16	2600	1.15	85	94	47.31	37.2	1.32	146	666	44	32.8	11.2	19.6	7.9	25.8	7.9	0.0
CK 44	2600	1.15	77	85	31.05	32.0	1.01	170	765	38	27.5	7.5	17.0	7.5	20.2	0.0	0.0
CI31A	3400	0.88	103	106	72.8	89.5	1.65	173	661	74	18.2	7.3	7.3	7.3	14.5	0.0	0.0
CO266	2700	1.10	77	92	53.31	37.0	1.03	206	783	62	26.0	0.0	12.4	7.0	16.1	10.1	0.0
CM 7	2650	1.12	70	92	44.02	30.4	1.02	175	958	29	34.4	13.7	17.8	13.7	21.1	15.8	0.0
DE811	2900	1.03	100	106	73.86	85.2	1.75	80	358	22	30.7	8.3	17.0	14.7	22.7	8.3	0.0
MS72	2800	1.06	94	99	62.80	51.3	1.87	230	860	81	30.5	0.0	13.8	0.0	22.3	0.0	0.0
OH 43	3000	0.99	94	99	62.99	55.6	1.24	230	1092	68	27.0	10 1	16.2	7.3	17.9	12.5	0.0
CO273	2750	1.08	85	94	54.02	35.0	1.11	231	1225	89	30.0	6.8	22.1	6.8	23.2	0.0	0.0