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**HOST PLANT RESISTANCE AND EPIDEMIOLOGY
OF FUSARIUM EAR ROT IN MAIZE.**

by



Bernard Vigier

**A thesis submitted to the
School of Graduate Studies and Research,
University of Ottawa,
in partial fulfilment of the requirements for the
Degree of Doctor of Philosophy
in Biology**

1997



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ABSTRACT

This thesis examines fusarium ear rot epidemiology in maize (*Zea mays* L.) and host plant resistance to *Fusarium* species causing ear rot, in eastern Canada, through three major groups of experiments. A three-year disease survey that determines the causal agents of maize ear rot in Ontario; a three-year study on the stability of different genotypes to two different inoculation techniques across different environments; and a two-year study on fungal infection from an inoculum source using methods to detect infection spread.

A survey of maize ear rot was conducted in eastern and western Ontario from 1991-1993 in order to develop a predictive model of ear rot incidence. Field data were collected on disease incidence, insect and/or bird damage, ear tip infection (silk), rainfall, and temperature. Isolations were made in the laboratory from samples showing evidence of infection, and the five prevalent *Fusarium* species (*F. graminearum*, *F. moniliforme*, *F. proliferatum*, *F. sporotrichioides*, and *F. subglutinans*) were enumerated. The profile of *Fusarium* species isolated varied considerably from year to year, and in a certain proportion between sites. *Fusarium subglutinans* was the most frequently isolated species and was associated with low rainfall in July. *Fusarium moniliforme* and *F. proliferatum* occurred mostly following the hot, dry summer of 1991. *Fusarium graminearum* presence increased significantly with higher precipitation in July. Presence of *F. sporotrichioides* was not associated directly with the incidence of ear rot. Insect damage and infection through the ear tip were the most important modes of fungal entry into maize ears. A multiple regression model was derived from the survey data and tested on results obtained with independent maize genotype trials naturally infected with fusarium ear rot. Causal relationships between genotype x environment interactions and the adaptability of genotypes according to their resistance to ear rot and yield have been investigated over three consecutive years at 5 locations in 1994, and 6 locations in 1995 and 1996, over a set of 9 maize genotypes representing a range of gibberella ear rot resistance.

In the second major field study undertaken in east-central Ontario and south-western Québec, the interaction between genotypes and environments was described using a Joint Regression Model and an Additive Main effects and Multiplicative Interaction effects (AMMI) model. The AMMI model was able to capture 68% of the interaction across both inoculation methods, compared to 84% for the Joint regression model. The AMMI model shows in particular that genotype x environment interaction was associated with high September rainfall and the number of cool days (below 21°C) in August and September across the 17 environments. Variation in September rainfall explains 50% of the variation observed in ear rot ratings.

The number of cool and wet days (relative humidity over 80%) observed in August was more critical for silk channel inoculation infections, and the number of wet days was more critical to achieve severe ear rot with the kernel-stab inoculation technique.

A disease spread study showed that the Power Law model is a suitable model to predict fusarium ear rot spread over a distance below five metres from a small inoculum source of *F. graminearum* (strain DAOM 180378). A similar disease spread was found in maize planted in narrow or wide row spacings with aggregation patterns of diseased plants showing a positive inoculation response. An average steepness gradient of 0.7 m was found across ear rot ratings isolines. Wind had no effect on the disease spread nor orientation of infection patterns, suggesting that rain-splash would be the main inoculum transport factor for inoculum already present on plant residues on the plant surface as expressed by background infection levels. A 52% leaf area index increase was achieved with narrow row spacings compared to wide rows and positive correlations were found between the leaf area index and ear rot incidence during a low infection year.

Résumé

Cette thèse porte sur l'épidémiologie de la fusariose de l'épi du maïs (*Zea mays* L.) et sur sa résistance aux espèces de *Fusarium* qui provoquent cette maladie. Cette étude comporte les trois volets principaux suivants: une étude répartie sur trois années et qui détermine les principaux facteurs de la fusariose de l'épi en Ontario; une étude de trois années sur la stabilité de la résistance de différents génotypes à la fusariose de l'épi sous deux modes d'inoculation et dans différents environnements en Ontario et au Québec; et finalement, une étude de la dispersion de la fusariose de l'épi à partir d'un foyer d'infection provenant d'une souche de *Fusarium graminearum*, par des méthodes de détection de foyers d'infection.

Une étude a été réalisée, de 1991 à 1993, sur l'incidence de la fusariose de l'épi du maïs dans les régions de l'est et de l'ouest en Ontario afin de développer un modèle de prédiction sur l'incidence de la moisissure de l'épi. La collecte des données a porté sur l'incidence de la maladie et la présence de cinq espèces de *Fusarium* (*F. graminearum*, *F. moniliforme*, *F. proliferatum*, *F. sporotrichioides* et *F. subglutinans*). Le profil de distribution des espèces de *Fusarium* isolées a varié d'une année à l'autre et aussi parmi les différents sites. Le *Fusarium subglutinans* a été l'espèce dominante observée et sa présence a été associée à une faible pluviométrie en juillet. *Fusarium moniliforme* et *F. proliferatum* ont surtout été observés lors de l'été chaud et sec de 1991. La présence de *Fusarium graminearum* a augmenté de manière significative en fonction d'un accroissement de la pluviométrie en juillet. Les dommages d'insectes et les infections de la pointe de l'épi ont été les principales voies d'entrée du *fungus* sur les épis de maïs. Un modèle de régression à variables multiples a été calculé afin d'estimer l'incidence de la fusariose à partir des résultats de l'enquête. Ce modèle a été vérifié avec succès sur des essais indépendants de l'étude, constitués de cinq génotypes de maïs sous infection naturelle de fusariose de l'épi.

Le deuxième volet de l'étude réalisée dans les régions du centre-est de l'Ontario et du sud-ouest du Québec traite des interactions entre génotypes et environnements sur la résistance à la fusariose de l'épi. Deux modèles ont été utilisés pour quantifier ces interactions, soient le modèle nommé 'Joint Regression Model' et le modèle à effets principaux additifs et effets multiplicatifs des interactions (AMMI). Ce dernier modèle a pu capter 68% des interactions obtenues avec deux méthodes d'inoculation alors que le modèle de régressions conjointes a capté 84% des interactions. Le modèle AMMI a permis de constater qu'il existe un lien significatif entre l'interaction génotype x environnements et une pluviométrie élevée en septembre ainsi qu'avec le nombre de journées fraîches (en dessous du seuil de 21°C) observées en août et en septembre à travers 17 sites à l'étude. La variation pluviométrique en septembre explique 50% des écarts observés sur l'échelle de sévérité de la moisissure de l'épi. Le nombre de journées fraîches et humides (plus de 80% d'humidité relative) en août a été plus critique pour obtenir des indices de sévérité plus élevés avec la méthode d'inoculation à travers le canal des soies, alors que seul le

nombre de journées fraîches a été associé à une sévérité plus marquée obtenue avec la méthode d'inoculation par piquage direct des grains.

L'étude sur la dispersion de la maladie révèle que le modèle ci-nommé 'Power Law' est un modèle bien adapté à la prédiction de la dispersion de la fusariose de l'épi sur une distance inférieure à 5 mètres à partir d'une source d'inoculation ponctuelle provenant de la souche DAOM 180378 de *F. graminearum*.

La dispersion de la maladie a été semblable pour une culture de maïs en rangs étroits ou larges avec une aggrégation des épis attaqués qui témoignent de l'efficacité de l'inoculation. Un gradient de sévérité de la maladie de l'ordre de 0,7 mètre a été mesuré sur trois parcelles infectées à partir des grilles de sévérité. La dispersion éolienne qui n'a eu aucun effet visible sur l'orientation ou la dispersion des foyers d'infection, suggère que la dispersion des spores par éclaboussures des gouttelettes de pluie a été le moyen de transport le plus important à partir des résidus de plantes déjà infectés sur le sol comme en témoigne la présence d'infection naturelle. Un accroissement de l'indice de surface foliaire de l'ordre de 52% a été réalisé avec des rangs de maïs étroits de 45 par rapport à des rangs larges de 90 centimètres. Une corrélation positive a été obtenue entre l'indice de surface foliaire et l'incidence de la fusariose de l'épi durant une année à bas niveau d'infection.

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ABBREVIATIONS

AMMI	Additive main effects and multiple interactions model
CHU	Corn heat units
COL	Number of cool days per month with average temperatures below 21°C
CV	Coefficient of variation percentage
DAOM	Fungal strain registration code in the Canadian collection of fungal cultures
d ₅₀	Distance from inoculum source where disease rating is reduced by 50%
ENV=	Environment identifier
F	Analysis of variance F-value
<i>F.</i>	<i>Fusarium</i>
<i>G. zeae</i>	<i>Gibberella zeae</i>
GE	Genotype by environment
GENO	Genotype
GxE statistic	Lin and Binn's cultivar performance test statistics
HUM	Number of days per month with relative humidity over 80%
IPCA1	First score level of modified principal component analysis
IPCA2	Second score level of modified principal component analysis
MS	Mean squares value
N, n	Number of observations
P	Probability level
PC	IBM compatible personal computer
PCA	Principal component analysis score
r	Correlation coefficient
R-	Maize maturity stage according to the 'Ritchie scale'
R ²	Coefficient of determination
RN	Number of days per month with rainfall
R.H.	Relative humidity
RMSE	Root mean square estimate
spp.	Species
SE	Standard error
SS	Sum of squares value
S-3	Model of ear rot incidence with variables based on 3-level scores
S-100	Model of ear rot incidence with variables based on percentages
TRT=1	Treatment 1 or silk channel inoculation
TRT=2	Treatment 2 or kernel-stab inoculation

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CHAPTER I

GENERAL INTRODUCTION

1.1 Economic loss from plant diseases

New findings concerning populations of plant pathogens such as fungi, bacteria, viruses, viroids, nematodes, and their repercussions on plant disease progress is of outmost importance in agriculture. Economic loss through the impairment of cereals alone can achieve staggering levels. About 10 percent of the world's grain production is lost through diseases, and another 25 percent is lost through insect damage and competition with weeds (Agrios 1988). The most severe disease loss for maize in the USA reached a billion dollars during the 1970 southern corn leaf blight epidemic caused by *Bipolaris maydis*. In developing countries, leaf blight of rice (*Helminthosporium oryzae*) has translated into loss of two million lives from starvation, during the great Bengal famine in the 1940's. More recently, in Ethiopia, ergot in rye caused by *Claviceps purpurea* resulted in human suffering and death due to the consumption of infected grain (Campbell and Madden 1990).

In Canada, rust disease (*Puccinia spp.*) in wheat has been a problem for over fifty years. *Fusarium* head blight, a fungal disease in wheat, has been encountered about every nine years since the 1940's (Sutton 1982). The latest epidemic in wheat occurred in 1986 and had a serious impact on grain quality, because roty grain was contaminated with mycotoxins. These toxins, mainly zearalenone and deoxynivalenol, are toxic to both humans and animals when grain is consumed as food or feedstuffs. The same soil-born fungi, mainly *Fusarium* species, can also induce ear rot in maize. In a normal year, in maize alone, the direct economic loss attributed to deoxynivalenol (2 ppm and above) for the animal feed industry represents a 4 percent loss or 280,000 metric tons. After an epidemic year, mycotoxins can contaminate up to ten percent of maize produced in Quebec and Ontario (Food Production and Inspection Branch 1995).

1.2 Disease resistance and plant breeding

Resistance in agricultural systems can be defined as the ability of an organism to withstand or oppose the operation of or to lessen or overcome the effects of an injurious pathogen factor (Federation of British Plant pathologists 1973).

Host plant resistance to pathogens is variable among species and varieties and under different environmental conditions (Fig. 1.1). A susceptible variety within a plant species will display severe disease symptoms to a particular pathogen, while another variety will demonstrate tolerance and maintain growth and performance despite infections (Agrios 1988). Moderate resistance to a pathogen starts at the molecular level with a series of metabolic reactions, generally through cellular necrosis, undertaken to neutralize pathogen entry. It can be achieved through detection of the invading pathogen by the activation of hypersensitive cells or modification of cell walls to act as a barrier to infection (Campbell and Madden 1990). Defense mechanisms can also be triggered by secondary metabolites produced by the plant.

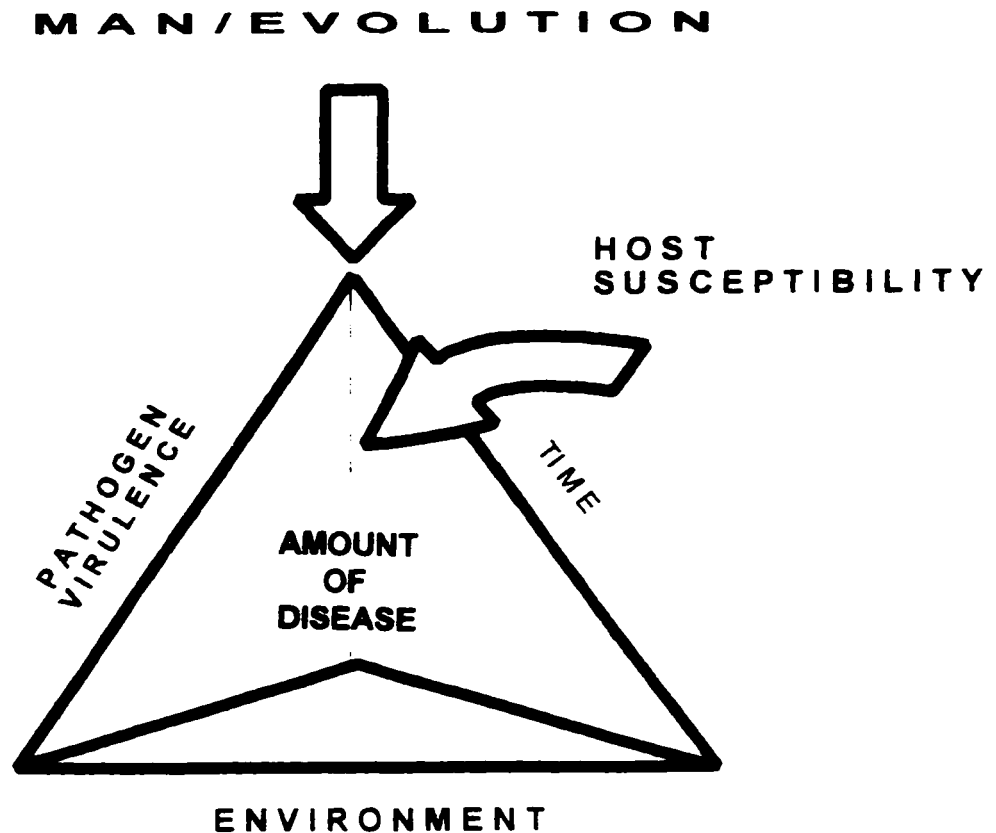
The ability of a resistant variety to escape the disease or tolerate the effects of a disease is an important component of host plant resistance. Disease escape or tolerance to a pathogen lead to significant levels of resistance in the host plant and tend to be naturally expressed. For example, ergot, a fungal disease of the inflorescence in wheat, does not attack varieties which have flowers that remain closed until pollination and act as a physical barrier to infection. This passive resistance trait is independent of the presence of the pathogen, however it may be active in an evolutionary sense if it resulted from a past selection due to pressure by the pathogen. Breeding for resistance to a fungal pathogen can take two routes: one can rely on pre-existing resistance (before an infection), such as lignified cell walls that are difficult to degrade by a pathogen or difficult degradation by a pathogen's enzyme or one can rely on a responsive resistance mechanisms, activated by inoculation, such as a rapid deposition of compounds near the point of infection to resist hyphae penetration, or the secretion of chemical compounds with fungi-toxic properties.

Fig. 1.1. Pyramid of disease resistance.

The amount of disease depends upon the level of the pathogen virulence, environmental conditions that are favorable to its development, the host susceptibility and the duration (time) of the plant exposure to these conditions. Man intervention through breeding plants for host plant resistance or plant capacity to adapt through evolution will have an impact on the amount of disease.

(Adapted from Agrios 1988)

PYRAMID OF DISEASE RESISTANCE



Adapted from Agrios (1988)

There are three major sources of resistance in plants that are controlled at the genome level. One is monogenic, in which case the defense mechanisms are controlled by one or a few genes (oligogenic) and are classified as specific or vertical resistance. The second one, which is associated with horizontal or general resistance, is polygenic and relies on a group of complementary genes acting in synergy to control the disease. In the third instance, a cytoplasmic resistance source is derived from genes located in the cytoplasm that can defend against the invading organism, e.g. southern leaf blight resistance in maize.

1.2.1 Fungal diseases in plants

Fungal diseases in crop production lead the way in terms of damage severity to the agricultural economy. There are about 200 fungi that are serious pathogens to agricultural plants. Parasitic fungi are of two kinds: biotrophic and necrotrophic. Biotrophic fungi depend on the survival of the plant host in order to have a lasting source of nutrients and necrotrophic fungi kill its host plant cells (Russell 1978).

1.3 The *Fusarium* genus

Fusarium constitutes a major genus of soil-borne fungi of pathological importance across the world. The genus was discovered in 1809 by Link, and first characterized in 1910 by Appel and Wollenweber through its typical pluricellular crescent shape macroconidial formation. It belongs to the higher fungi or Amastigomycota division. The literature on *Fusarium* pathology is large and encompasses more than twenty species parasitic to plants, while another twenty are considered to be mostly saprophytic (Price 1984).

Fusarium species are classified as imperfect fungi or Deuteromycetes in the Moniliales order. Different taxonomic systems have been used to identify and classify *Fusarium* species since Wollenweber, Snyder and Hansen (1945) proposed a system that was accepted by many (Messiaen and Cassini 1968). The most recent taxonomic system was developed by Nelson (1980) and is the most currently used (Burgess et al. 1994).

Nelson's *Fusarium* species identification is essentially based on a combination of microscopic and colony characters. It has 12 sections separated by forms, coloration and different characterizations like macroconidia shape and size, presence of chlamydospores, presence of microconidia in aerial mycelium, type of conidiophore, and mycelium color. Many species can alter genetically and become sac fungi (Ascomycetes class, Hypocreales order) with the production of sexual ascospores and develop characteristics associated with the *Gibberella* genus. Depending upon environmental conditions, some *Fusarium* species can achieve genetic change by sexual, parasexual or heterokaryotic means. *Fusarium* populations exist as chlamydospores in soils, crop residues, or plant roots. The best known species that are characterized by a teleomorphic stage are *F. graminearum* and *F. subglutinans*. These asexual *Fusaria* can reproduce through conidial formation (Snyder 1969). *Fusarium graminearum*, *F. subglutinans* and *F. moniliforme* can achieve perfect states and are classified as part of *Gibberella*, species *zeae* (Sch.) Patch., *subglutinans* (Edwards) Nelson et al. and *fujikuroi* (Sawada) Ito, respectively. *Gibberella* is characterized by sexual spores (ascospores) contained in perithecia formations on the host (Burgess et al. 1994). These ascospores are air-borne in their dispersal.

Most of the diseases caused by *Fusarium* spp., such as fusarium root rot caused by *F. solani* in plants, are very difficult to control but can be reduced by adapted cultural practices, (Vigier and Raghavan 1980; Vigier et al. 1983). Other diseases caused by *Fusarium* spp. are, the wilts caused by *F. oxysporum*, different types of stalk or grain rots caused by *F. graminearum*, *F. moniliforme*, *F. proliferatum*, *F. subglutinans*, *F. avenaceum*, *F. culmorum*, *F. sporotrichioides*, and *F. crookwellense*. All these *Fusaria* can survive in the absence of a host in soil debris or residues from infected plants. *Fusarium oxysporum* can have an overwinter survival rate in the range of 40% from fall to spring and it is suggested that no-till agriculture may have an impact on pathogen persistence on plant debris (Thrall 1997). In the context of host pathogen population biology, the same author reports the difficulty of studying the carrying capacity of a host according to its density in an agricultural production system. Long term studies in natural conditions where fungal attack on plants can lead to a co-existence equilibrium cannot be studied in agriculture.

1.4 Ear rot in maize

In eastern Canada, over one million hectares of farm land are devoted to the production of high quality maize (*Zea mays* L.). However, crop quality is affected by two distinct ear rots. The first is gibberella or pink ear rot, which is observed during wet years and caused by *F. graminearum*, Schwabe (teleomorph = *G. zeae* (Sch.) Patch, Ascomycetes) group II. This group predominates in warm humid areas (Francis & Burgess 1977). The other disease, fusarium ear rot or kernel rot, is attributed to *F. moniliforme* Sheldon, although *F. proliferatum* (Mats.) Nirenberg and *F. subglutinans* (Wollenw. & Reining) also cause similar symptoms (Nelson et al. 1983).

In maize, gibberella ear rot has been observed at epidemic levels in eastern Canada in the seventies (Sutton 1980; Sutton et al. 1982). Later in the 1980's, epidemics appeared again on wheat and maize in 1986 with outbreaks resulting in mycotoxin contamination which led to animal growth disorders (Miller 1994). *Fusarium graminearum* was found to be the causative agent in these epidemics.

Ear rot control can be achieved with adapted cultural practice through ploughing under and burial of infected crop residues and avoiding the repetitive use of susceptible crops such as cereals. However, severe ear rot has been observed in some years in eastern Canada, even following these practices. The more current cultural practice of leaving crop residue on the soil surface (reduced tillage) may increase the problem (Teich & Hamilton 1985; Klaasen et al. 1991). The most satisfactory and economical means of controlling ear rot is the use of resistant maize hybrids (Reid et al. 1992, 1993; Reid & Hamilton 1995). A recent study reported that late maturing and mid-late maize lines were more resistant to *F. graminearum* than early lines (Palaversic et al. 1991).

1.4.1 Maize silk and kernel resistance

Maize fungal resistance mechanisms against ear rot have been associated with barriers against spore entry into the plant. The silk channel has been recognized as a major pathway for fungal infections and a maize breeding program for gibberella ear rot

resistance has been oriented towards silk resistance (Reid et al. 1993). For gibberella ear rot, a vertical resistance mechanism was found recently, through the action of a single gene identified as 'fgs1', giving maize silks the property of resistance against *F. graminearum* entry through the ear silk channel (Reid et al. 1994). Entry into the maize ear can also be achieved through kernel wounds created by insects or birds (Sutton et al. 1980). The association between *F. graminearum* kernel resistance and secondary metabolites, such as (E)-ferulic acid, has been demonstrated (Assabgui et al. 1993). Improved resistance at this level through enhanced pericarp architecture, thickness, and secondary chemicals could also lead the way for resistance studies.

In addition to the loss in yield caused by these diseases, mycotoxin contamination of infected grain is a serious concern for both human and animal health. Mycotoxins produced by *F. graminearum* include the teratogen deoxynivalenol (vomitoxin) and the estrogen zearalenone. *Fusarium moniliforme* and *F. proliferatum* both produce carcinogenic fumonisins (Miller et al. 1995).

1.5 Epidemiology of phytopathogenic fungi

"Plant disease epidemiology is the study of temporal and spatial changes occurring during epidemics of plant disease caused by populations of pathogens in populations of plants" (Campbell and Madden 1990).

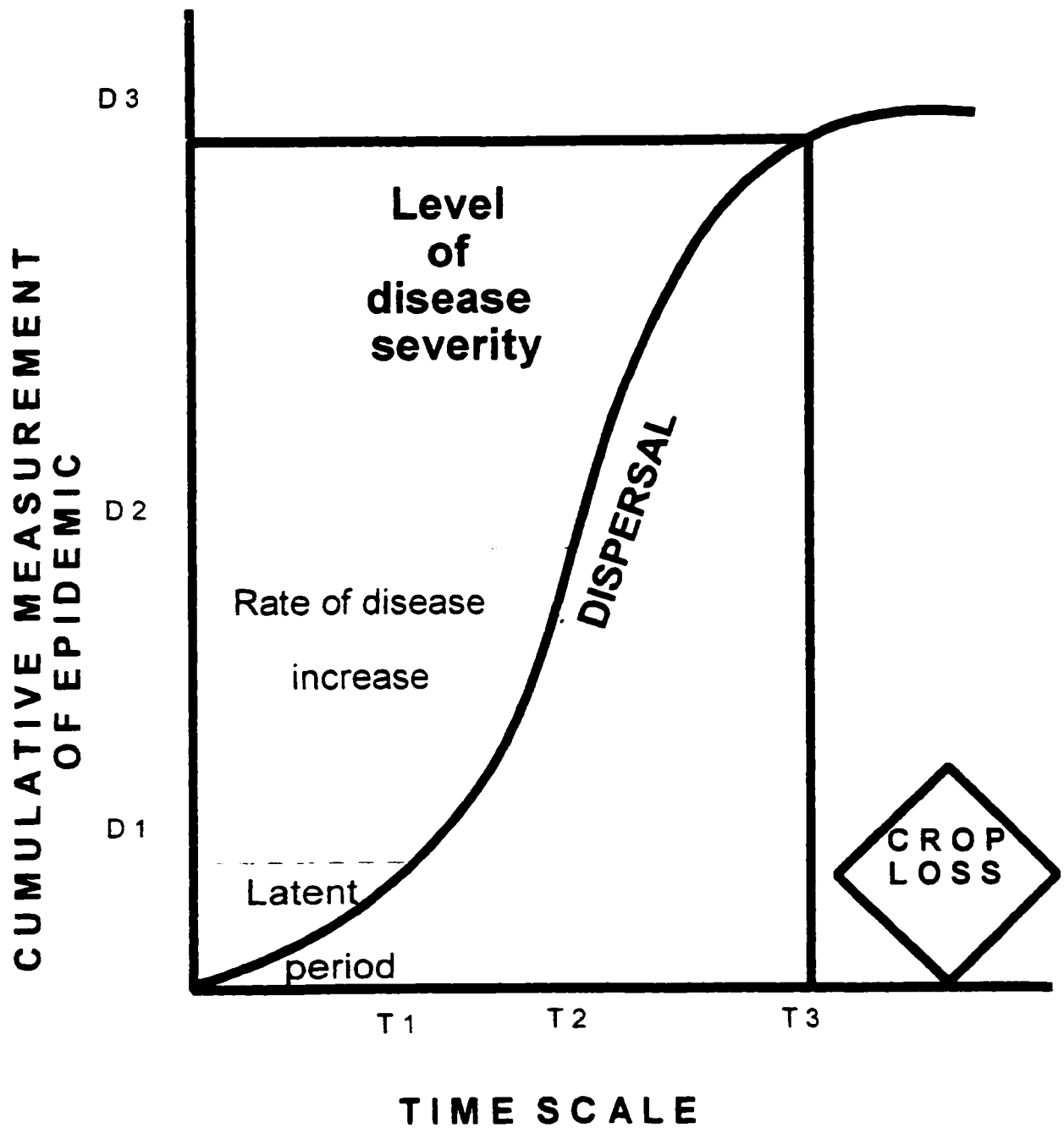
Basically, for fungal diseases, an epidemic starts with a source of infection followed by a latent period of infection or incubation period, before a typical epidemic is declared (Fig. 1.2). The infection cycle of phytopathogenic fungi can be studied mathematically in time and space. Quantitative methods have been proposed to study plant disease epidemics (Van der Planck 1966, 1982; Butt and Royle 1990). Levels of disease severity can be observed through surveys or simulation of infections. These infections can be induced through artificial inoculations of a particular spore suspension of fungi injected on a host.

Fig. 1.2. Features of a plant disease epidemics.

The cumulative measurement of an epidemic can be monitored through 4 phases: the latent period during which a certain level of spore development must be reached before propagule dispersal can start. This dispersal induce an increase in disease incidence that reach a certain level of severity that can reduce grain yield in agricultural crops at harvest

(Adapted from Butt and Royle 1990)

FEATURES OF A PLANT EPIDEMICS



Adapted from Butt and Royle (1990)

Different approaches for the study of epidemics have been proposed. Some focus on the rate of disease increase and changes in disease severity in time and in relation to environmental factors. Others are directed at factors associated with the level of disease severity at a particular point in time or target a particular event in the disease cycle.

1.5.1 *Fusarium* epidemiology

Surveys in Indiana during epidemic years in the early seventies have found an association of gibberella ear rot with temperature and rainfall (Tuite et al. 1974). Ideal disease development conditions appeared to be when the temperature is less than 23° C during the silking stage with nine consecutive days of rainfall. Gibberella ear rot is spread mainly through inoculum sources in plant debris. *Fusarium graminearum* can survive in old stalks and ears of maize, stubble or debris of wheat and barley and other cereals (Sutton 1982).

1.5.2 *Fusarium graminearum* propagation

There are four types of *Fusarium graminearum* propagules: sexual ascospores, asexual macroconidia that can transform into thick-wall chlamydospores in the soil, and hyphae fragments from mycelium. The conidial stage of *Gibberella zeae* (Sch.) Patch has been well investigated since it is a key for taxonomic identification and the main propagule of *F. graminearum*.

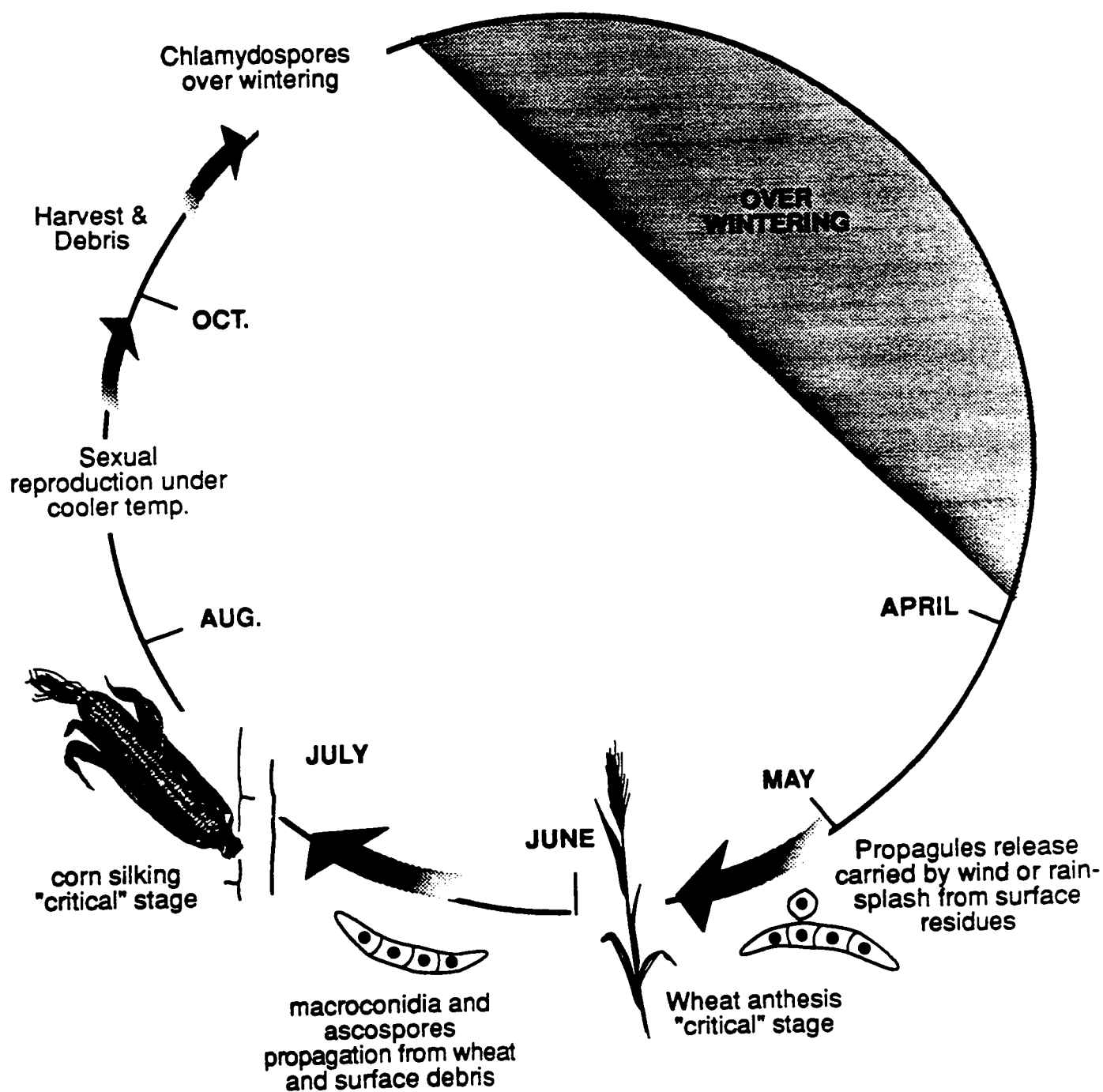
The ability of *Fusarium* species to overwinter in crop residues from different agricultural crops such as corn, wheat, barley, and other cereals has made this species difficult to control (Khonga and Sutton 1988). An epidemiological cycle of *Fusarium* species has been described earlier (Sutton, 1982). The propagation of *Fusarium* propagules is associated with critical growth stages in its hosts that caused fusarium ear rot (Fig. 1.3). Two types of inoculum sources have been associated with *Fusarium graminearum*, they are ascospores which are relatively uniform in size with three to four septa, and macroconidia, variable in size and septation but with a typical falcate and slender shape and a distinct foot shaped basal cell (Burgess et al. 1994). The specific

Figure 1.3. Disease cycle of fusarium ear rot in humid regions.

Fusarium propagules are released in May after overwintering as chlamydospores. They are carried by wind or rain-splash from surface residues and they are deposited on wheat at anthesis in June where they infect the pollen and the grain. Wheat residues provide a secondary source of inoculum that will infect corn at the critical silking stage in late July and early August. The kernels will be infected and develop fusarium ear rot symptoms at harvest in late September for early maturing maize. Cooler temperatures in October will induce a sexual reproduction specially in *Fusarium graminearum* and most likely in *F. subglutinans*. Propagules will overwinter as chlamydospores or macroconidia on debris left on the soil surface.

(Modified from Sutton 1982).

***Fusarium* ear mold propagation**



reproductive modes are illustrated in Fig. 1.4. More recently, it has been possible to identify strains within a species using DNA-fingerprinting techniques that are less time-consuming than pathogenicity tests required on a range of hosts (Ouellet and Seifert 1993). These methods, already developed for identification of specific *F. graminearum* strains, allow the tracking of a particular strain in the field without the use of a mutant strain.

1.5.3 Spore dispersal and spatial gradients

Many mechanisms are involved in the movement of plant pathogens. Fungal spores are ejected in the air and are transported through the action of wind, insects, rain-splash, water run-off, infested plant residues left after harvest, and man made agricultural equipment. The study of spore dispersal events implies a temporal factor or a progression in time. Spatial analysis of disease dispersal gives a static representation of an event in time and if repeated at time intervals, can provide a spatial-temporal analysis (Campbell and Madden 1990). Inoculum sources are placed into three categories: point source, line sources, and area sources. Principles of dispersal gradients that have been developed assume the presence of a local source of inoculum with a population of susceptible hosts. A secondary dispersal and a background infection from other pathogenic sources can hinder the visibility of a primary infection gradient, and a multiple infection must be assumed and be analyzed accordingly (Gregory 1968).

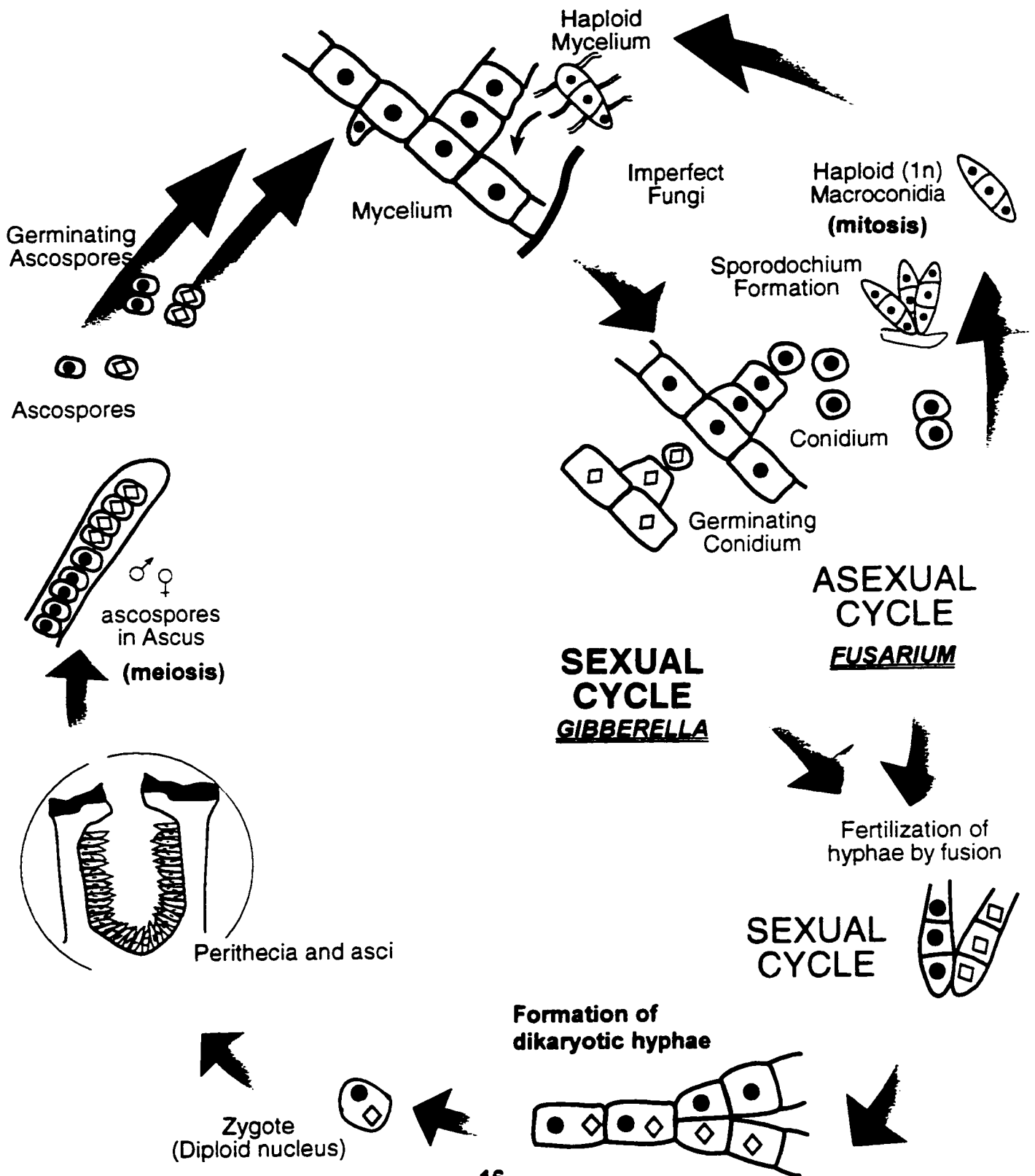
1.6 Environmental variability and disease resistance

In the domain of field experimentation and plant breeding for disease resistance, the environmental variability of resistance components brings frequent errors of judgement (Zadoks and Schein 1979). It is the role of the epidemiologist to calculate the outcome of a particular level of resistance in different environments and to support the plant breeder in making selective decisions to choose the best genotype with moderate resistance for a particular region.

Figure 1.4. Reproductive cycles of *Fusarium* and *Gibberella* species.

After initial propagule dispersal, two reproductive cycles can start depending on favorable environmental conditions. The asexual cycle (*Fusarium* spp.) starts at 20 - 25° C from dispersed conidia that initiate macroconidia in a sporodochium formation on plant debris. The haploid macroconidia, after mitosis, are dispersed on a plant host where they develop appressoria and hyphae that will cause fusarium ear rot. On the other hand, under cooler temperature a sexual cycle (*Gibberella* spp.) will start with the the fertilization of hyphae by fusion and the production of dikariotic hyphae. The cells will produce a fruiting body on plant debris (perithecia) with diploid ascospores. After meiosis, ascii are released and dispersed on a plant host where they will develop appressoria and hyphal growth leading to gibberella ear rot in maize.

REPRODUCTION CYCLE OF FUSARIUM AND GIBBERELLA SPECIES



1.6.1 Genotype x environment interactions

Genotype x environment interactions were first reported by Yates and Cochran (1938) in genotype evaluation trials, leading to many different quantitative genetic studies over the years. The purpose of this statistical analysis was to help the plant breeder in the selection of superior genotypes that could perform well across a range of environmental and agronomical conditions. The calculation of this interaction was a first attempt at explaining why some genotypes performed well at a particular location and not in another. More recently, statisticians have developed stability parameters to predict the potential variation of a particular genotype in different environments (Freeman 1973; Mather and Caligari 1974; Westcott 1986; Lin and Binns 1988). It has been shown clearly that the external environment can influence the phenotypic expression of a given genotype.

The variability of a resistant trait and its expression can be associated with the genotypic sensitivity to an environmental disturbance and can be expressed by a phenotypic plasticity response (Fritz and Simms 1991). The plasticity of many resistance traits will increase the dependability of a genotype over a wide range of environmental conditions.

1.7 Hypotheses and Objectives

1.7.1 First hypothesis

Disease epidemiology theory suggests that a fungal disease complex and its relation to weather conditions at critical plant growth stages, at anthesis and early formation of kernels, will change over years. Therefore it is hypothesized that the disease complex found in the nineties is different from that described in the mid-eighties, which declared that *Fusarium graminearum* is the major *Fusarium* species associated with ear rot in Ontario and vector transmission through feeding insects and birds is important (Sutton et al. 1980; Sutton 1982; Kongha and Sutton 1988).

Interest in other *Fusarium* species has been triggered by the identification of new mycotoxins such as fumonisins in maize kernels infected with *F. moniliforme* and *F.*

proliferatum. It is proposed that a linear regression analysis of most recent survey data available can estimate the contribution of the different *Fusarium* spp. to ear rot incidence.

1.7.2 Second hypothesis

It is hypothesized that novel resistance traits found in silks against *F. graminearum* infection identified in inbred line CO272 and the trait found in kernels for inbred CO325 are expressed independently of external environmental conditions. This hypothesis suggests that resistance can be physical in nature. The silk resistance to ear rot appears to be linked on the presence of cuticular waxes which are likely to be stable over many environments (Reid et al. 1992a; 1992b; 1994). Kernel resistance to ear rot has been also observed and associated with the presence of several genes (Chiang et al. 1987; Chungu et al. 1996).

In any case, the stability or plasticity of these two modes of resistance must be established before these genotypes can be released for extensive commercial maize hybrid production. Rating scales of infection levels that have been developed can help to verify this hypothesis through genotypic field evaluations done over years at different locations. Generally in agricultural systems, a stability analysis is based on genotype yield deviation from an environmental index. The present approach has never been attempted before, it also incorporates the analysis of the genotypic resistance visual symptoms observed before harvest.

1.7.3 Third hypothesis

Little is known about *Fusarium graminearum* dispersal in a field situation and how plants are infected with ear rot. It is hypothesized that weather conditions and plant population variation achieved with two row spacings have an effect on ear rot infection when a *Fusarium graminearum* inoculum source is applied from a point source inoculation. It is assumed that it is possible to develop a disease spread model for a short distance with presence of background infection levels from other *Fusarium* spp. in the field.

An attempt was also made in collecting propagules from the same inoculum source

to monitor the effect of wind direction and distance from the source on spore dispersal. Finally, it is hypothesized that propagules from a particular *Fusarium graminearum* strain can be tracked on maize silks and kernels with DNA fingerprinting techniques and can be associated with observed fusarium ear rot.

1.7.4 Research objectives

The above three field studies provide new knowledge in maize ear rot epidemiology and resistance mechanisms. An assessment of the contribution of fusarium ear rot to the overall severity of ear rot has been done. The evaluation of secondary damage caused by feeding insects and birds as well as environmental factors such as temperature and rainfall in association with the level of disease incidence give an estimate of their importance as vectors in disease propagation. The dependability of a monogenic silk resistance trait to *Fusarium graminearum* found in new inbred lines has been tested. The resistance expression of waxy silks on a genotype is assumed to be passive because it does not appear to be triggered by the presence of the pathogen. Kernel resistance mechanisms could be linked to another passive trait, i.e. the ability of kernels to mature more rapidly and act as a physical barrier against pathogen invasion. The resistance plasticity of both traits has been investigated across different external environmental conditions. The impairment of pathogen dispersal through different host plant planting densities and resulting phenotypic variations may bring more insight in the area of adapted cultural practices to avoid severe infection levels and promote host plant tolerance to the pathogen.

1.7.4.1 Objective 1- Analysis of a three-year survey on maize ear rot

My first objective is to determine the major pathogens responsible for ear rot in Ontario and to investigate the significance of environmental parameters on ear rot incidence. I intend also to investigate the significance of rainfall, temperature, insect and bird damage, and infection through the silk channel (ear tip infection) on disease incidence, and to develop a mathematical model to predict ear rot incidence.

Environmental parameters such as rainfall and air temperature are used to develop

the model along with secondary damage (birds/insects) observed on maize kernels, type of infection, and presence of *Fusarium* species identified by standard isolation procedures. The best statistical stepwise regression is achieved by computing the above variables to give an estimate for ear rot incidence (Steel and Torrie 1980; SAS 1988). The regression model is tested on independent data collected under natural ear rot infection levels and over a range of environmental conditions. A special emphasis is put on *Fusarium* species that can produce mycotoxins (deoxynivalenol, zearalenone, fumonisins) such as *F. graminearum*, *F. moniliforme*, *F. proliferatum*, *F. subglutinans*, and *F. sporotrichioides*.

Weather variables such as monthly rainfall, minimum and maximum temperatures, and long-term averages are obtained from three meteorological stations in each region under investigation. These weather stations are located in Ridgetown, London, and Woodstock for the south-west and Belleville, Kemptville and Ottawa for the central-east region. The regression model is tested on independent data collected from genotypic evaluation trials carried out at three different locations in 1992 and 1993.

1.7.4.2 Objective 2 - Genotypic resistance and environment interactions

My second objective is to determine the source of interactions in genotype by environment studies on the stability of gibberella ear rot resistance of four inbred lines and five hybrid maize genotypes, and to compare two statistical methods of partitioning the genotype by environment interactions.

The stability of ear rot resistance is evaluated with two methods of inoculation: the silk channel and kernel-stab techniques. The evaluation is performed across four inoculation treatments: silk channel inoculation, kernel inoculation, inoculation with water (control), and natural infection without any inoculation. The assessment is done using a visual rating scale ranging from 1 to 7, where 1= no infection and 7= >75% of the kernels visually roty at harvesting time, and an analysis of grain yields across the trials. The two inoculation methods have recently been developed to measure two types of disease

resistance: firstly, the resistance to initial penetration by the silk channel, and secondly the resistance to the spreading of the pathogen in host tissue through an artificial wound on maize kernels (Reid and Hamilton 1996a; Reid et al. 1996b).

Stability analysis has been used in the past by cereal breeders to select the most reliable genetic material based on grain yields. However, this analytical method has not been used often in disease resistance studies. Therefore a stability analysis is performed on both gibberella ear rot susceptible and moderately resistant genotypes across different environments.

Disease resistance and grain yields are analyzed according to a stability analysis approach initially developed by Yates and Cochran (1938). This approach consists of an analysis of variance combined with linear regression analysis between each genotypic performance measurement and the overall mean results obtained across all genotypes at a particular environment (Roth 1995). The slope of the regression line (b) describes the stability of yield performance and the disease resistance response to environmental changes but in a different way. A genotype with a small b value ($0 < b < 1$) will indicate good stability for disease resistance across different environments, but a genotype with $b \geq 1$ will show a good stability for yield.

1.7.4.3 Objective 3 - Disease spread and study of *F. graminearum* in the field

The third objective aims at the identification of the effect of maize planting methods with two different row spacings on the spread of ear rot from a *Fusarium graminearum* inoculum source, and to investigate the effect of environmental factors on the development of ear rot and yield.

A field study is carried out on the effect of spacing between rows on plant phenotypic characters and on the severity of ear rot. This experimentation follows methods established for field experimentation in epidemiology (Campbell and Madden 1990). The

study also attempts at assessing the duration of spore incubation period before sporulation (latent period) , and the duration of spore dispersal.

The inoculation is done at the beginning of the silking stage with a fusarium ear rot susceptible maize inbred CO266. Planting and agronomic practices are done according to conventional methods used by corn producers in eastern Canada. Aerial irrigation is supplied following two consecutive dry days to promote fungal growth. This experiment allows the measurement of fusarium ear rot spread in natural conditions over small areas. The analysis is made considering the effects of phenotypic measurements such as plant height and leaf area. The severity of infections is estimated at plant maturity. Contour mapping techniques are used to map isolines of plant infections from the source to identify the presence of infection foci. The mapping of the disease spread allows the calculation of a disease gradient from a data point interpolation technique called 'the natural neighbor interpolation' (Watson 1988).

Ascospores and macroconidia released from the point source and dispersal at plant height are collected with a series of 'stake traps' arranged in a fan pattern from the source at 1.5, 3.0, and 5.0 meters distance on the north, north-east, and east directions. Each stake trap consists of a microscope slide coated with petroleum jelly, snapped at a 45-degree angle on a 1 meter high bamboo stake. Coated slides are collected at intervals after a two-day exposure to propagule dispersal.

The DAOM 180378 strain propagules and other *Fusarium graminearum* strains will be collected on silks and kernels and measured with an established DNA finger-printing technique, using RAPD and PCR amplification techniques recently developed for tracking different *Fusarium graminearum* strains in the field (Ouellet and Seifert 1993). Background *Fusarium* species are also sampled to establish the importance of other species to the fusarium ear rot complex.

CHAPTER II

DISTRIBUTION AND PREDICTION OF *FUSARIUM* SPECIES ASSOCIATED WITH MAIZE EAR ROT IN ONTARIO

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2.1 INTRODUCTION

In eastern Canada, over one million hectares of farm land are devoted to the production of high quality maize (*Zea mays* L.) and 6.9 million tonnes of maize are harvested annually in Ontario and Québec (Statistics Canada 1995). This tropical crop was almost non-existent in cool temperate and cool regions in the mid-sixties. Newly introduced hybrid lines offered a narrow gene pool that made them vulnerable to some devastating epidemics in the early seventies. Recently, toxic rots have plagued maize production in Canada and across the world (Miller 1994). Infected grain can release mycotoxins that can cause reproduction disorders and growth reduction in farm animals fed with contaminated maize kernels.

Grain quality can be affected by two distinct ear rots. *Gibberella* or pink ear rot, is observed during wet years and is caused by *Fusarium graminearum*, Schwabe (teleomorph = *Gibberella zeae* (Sch.) Patch, Ascomycetes). Francis and Burgess (1977) described two populations of *F. graminearum* that differ in their ecology, pathology, and ability to produce perithecia. Group I causes a stalk rot in wheat in arid areas that has not been observed nor reported in Ontario. Group II causes *Gibberella* ear rot in maize and head blight in wheat, and it produces abundant perithecia on the host and in culture, and is the population associated with Ontario crops. Fusarium ear rot or kernel rot is attributed mostly to *F. moniliforme* Sheldon, although *F. proliferatum* (Mats.) Nirenberg and *F. subglutinans* (Wollenw. & Reining) Nelson et al. (1983) also can cause similar symptoms. This disease is often observed during warm and dry years (Sutton 1982).

Ear rot in maize is often accompanied by secondary damage caused by insects and birds on kernels (Sutton et al. 1980b; Sutton 1982; Miller 1994). *Fusarium graminearum*, *F. moniliforme* and *F. subglutinans* can also infect maize through the silk channel (Hellestine & Bothast 1977; Reid et al. 1992). In addition to the loss in yield caused by these diseases, mycotoxin contamination of infected grain is a serious concern for both human and animal health. Mycotoxins produced by *F. graminearum* include the teratogen deoxynivalenol (vomitoxin) and the estrogen zearalenone (Miller 1994). *Fusarium moniliforme* and *F. proliferatum* both produce carcinogenic fumonisins which are toxic to animal and humans (Miller et al. 1995).

Cultural practices recommended for ear rot control include plowing under of infected crop residues. However, even with these practices, severe ear rot has been observed in some years, in eastern Canada. The reduction in cultural practice associated with 'no-tillage' production systems which leave crop residue on the soil surface may increase the problem (Teich & Hamilton 1985; Klaasen et al. 1991).

The most satisfactory and economical means of controlling ear rot is the use of resistant maize hybrids (Reid et al. 1992; Reid et al. 1993; Reid et al. 1995). Since 1986,

Agriculture and Agri-Food Canada has been developing new inbred lines with improved resistance. To obtain a greater understanding of *Fusarium* epidemiology, annual surveys are necessary to monitor the yearly variation of *Fusarium* species in association with environmental conditions.

The main objectives of the current study are: (1) to determine the major pathogens responsible for ear rot in Ontario from 1991-1993; (2) to investigate the significance of rainfall, temperature, insect and bird damage, and infection through the silk channel (ear tip infection) on disease incidence; and (3) to develop a model to predict disease incidence.

2.2 MATERIALS AND METHODS

2.2.1 Field survey of maize hybrids

Surveys were performed from 1991-93 in late September or early October, shortly before harvest, in two of the major corn belts in Ontario. The first corn belt is located in south-western Ontario and the second one is mostly located in south-western Québec and east-central Ontario. The sites were selected following scouting reports by agricultural representatives in each area. In east-central Ontario, six counties were investigated, mainly along the north shore of Lake Ontario, and in the National Capital Region: Durham Co. (1 hybrid at 1 site, 1991 and 1992), Northumberland Co. (3 hybrids at 3 sites in 1991, 6 hybrids at 3 sites in 1992, 2 hybrids at 2 sites in 1993), Hastings Co. (1 hybrid at 1 site in 1991), Frontenac Co. (1 hybrid at 1 site in 1991), Lanark Co. (2 hybrids at 1 site in 1991), and Ottawa-Carleton Co. (23 hybrids at 4 sites in 1991). In south-western Ontario, ten counties were surveyed between Lake Huron and Lake Erie: Huron Co. (20 hybrids at 10 sites in 1991, 27 hybrids at 6 sites in 1992), Lambton Co. (5 hybrids at 3 sites in 1991, 2 hybrids at 2 sites in 1992, 1 hybrid at 1 site in 1993), Perth Co. (2 hybrids at 1 site in 1991), Oxford Co. (3 hybrids at 1 site in 1991), Hamilton-Wentworth (1 hybrid at 1 site in 1991), Kent Co. (1 hybrid at 1 site in 1992, 4 hybrids at 2 sites in 1993), Middlesex Co. (2 hybrids at 2 sites in 1992, 8 hybrids at 2 sites in 1993), Elgin Co. (27 hybrids at 6 sites in 1993), Waterloo Co. (4 hybrids at 1 site in 1993), and Wellington Co. (4 hybrids at 1 site

in 1993). Both sub-regions cover a corridor of about 500 by 125 km.

The majority of locations consisted of hybrid strip trials. Whenever possible, consistent hybrids were chosen for sampling across locations. At each location, the incidence of *Fusarium* infection was recorded visually on a sample of 40 primary ears per hybrid. When an ear appeared infected, the ear was further examined to determine the apparent mode of fungal entry, i.e. insect damage, bird damage, or ear tip infection by growth of the fungus down the silk channel. This information was gathered over 151 hybrids at 56 locations over a three-year period.

2.2.2 Sampling methods

Five kernels were collected from each visually infected ear and brought back to the laboratory for species identification. Kernels were surface sterilized in a 2.5% solution of NaCl for approx. 30 seconds, washed in tap water and plated on a selective medium, pentachloronitrobenzene (PCNB), (Nelson et al. 1983). Plates were incubated at 20-25°C for 7-10 days. Formed colonies were transferred to synthetic nutrient agar (SNA) with autoclaved filter paper and incubated at 20-25°C under a 12-hour photo period for 7-14 days with combined cool white fluorescent and near UV Westinghouse black light blue tubes. Cultures were identified according to the taxonomic concepts of Nelson et al. (1983). For analysis, the *Fusarium* species, isolated from a single ear, were pooled and considered as one sample.

2.2.3 Genotypic evaluations

Studies were conducted in three locations in 1992 and 1993, to evaluate the natural infection of five maize hybrids (Agri 501, Dekalb DK415, Pride K127, Pioneer 3737 and Pioneer 3953) which have variable resistance to *F. graminearum*. Agri 501 and Pride K127 are considered more resistant than the other hybrids tested. Hybrid maturities ranged from 2400 CHU (Corn Heat Units) for Pioneer 3953, 2550 CHU for Pride K127, 2950 CHU for Dekalb DK415, and 3000 CHU for Pioneer 3737.

Two western trials were located in Kent county (Ridgetown College-RCAT) and Lambton county (Arkona). An eastern trial was located in Hastings county (Stirling) in 1992 and a central trial in Northumberland county (Alderville) in 1993. Each trial was arranged in a completely randomized design with eight single-row replicates of 30 plants each. At harvest, each ear was examined and data were recorded as described above for the survey.

2.2.4 Environmental variables across locations and years

Monthly rainfall, and minimum and maximum temperatures for the years of the survey and long-term averages for the 30 years prior to the survey were obtained from three meteorological stations in each region, i.e. Ridgetown, London, and Woodstock for the west and Belleville, Kemptville, and Ottawa for the east.

2.2.5 Variable transformation and statistical analysis

Field survey data were analyzed using SAS version 6.03 procedures CORR and STEPWISE (SAS Institute INC 1988). Pearson's correlation coefficients were used to determine correlations with ear rot incidence for observed *Fusarium* species, insect and bird damage, ear tip infection occurrence, monthly air temperatures, and rainfall. Variables and ear rot incidence were tested in a multiple stepwise regression analysis in an attempt to develop an empirical mathematical equation for the incidence of ear rot.

The model is based on the presence of five major *Fusarium* species: *F. graminearum*, *F. moniliforme*, *F. proliferatum*, *F. subglutinans*, and *F. sporotrichioides*. Other minor *Fusarium* species such as *F. avenaceum*, *F. equisiti*, *F. oxysporum*, *F. poae*, and *F. semitectum*, were grouped together.

The presence of insect and/or bird damage and indications of ear tip infection were also used as variables in the models and were recorded, along with the presence of *Fusaria* isolates, as percentages. Variable levels were also transformed into a 3-level score: absence=0, 1-50%=0.5 level, and over 50%=level 1.

Data collected from the genotypic evaluation study was used to test the model developed from survey data. A three-level score transformation was necessary to adjust the model to the different sampling method used in these independent trials. The three-level score described earlier was adapted to these genotypic studies, where level 0 was recorded as absence of *Fusaria* in all eight one-row replicates, level 0.5=presence in one to four replicates, and level 1=presence in more than four replicates.

2.3 RESULTS AND DISCUSSION

2.3.1 Field survey and presence of *Fusarium* species isolates

The weather varied considerably between the three years of the survey. The first year, 1991 was a hot and dry summer with above average temperatures and below normal precipitation recorded at all weather stations. In 1992, conditions were reversed, with below average temperatures and above average precipitation. The 1993 season was the most typical, with average temperatures and precipitation throughout the province (Fig. 2.1). Epidemics of Gibberella ear rot are reputed to occur in warm, wet years and none of the years surveyed fit those criteria. *Fusarium* species isolates and percentage of maize ears showing visible symptoms of infection for each county surveyed between 1991 and 1993 are reported in Table 2.1.

More severe ear rot incidence levels were recorded in east-central Ontario, with a 16% average in 1991, 17% in 1992 and a 23% peak in 1993 observed on a small two-hybrid sample in Northumberland county. The five most common *Fusarium* spp. isolated from kernel samples were isolated on a total of 441 ears in the west and 539 ears in the east-central region.

Figure 2.1. Mean monthly minimum, maximum temperatures (°C), cumulative monthly rainfall (mm) and long-term average at three weather stations in south-western (London, Ridgeway, Woodstock) and east-central Ontario (Belleville, Kemptonville, Ottawa Central Experimental Farm) over 1991-93 period: **a)** maximum temperatures, **b)** minimum temperatures, **c)** cumulative monthly rainfall in the south-west; **d)** minimal temperatures, **e)** maximum temperatures, **f)** cumulative monthly rainfall in the east-centre. Bar represents standard deviation.

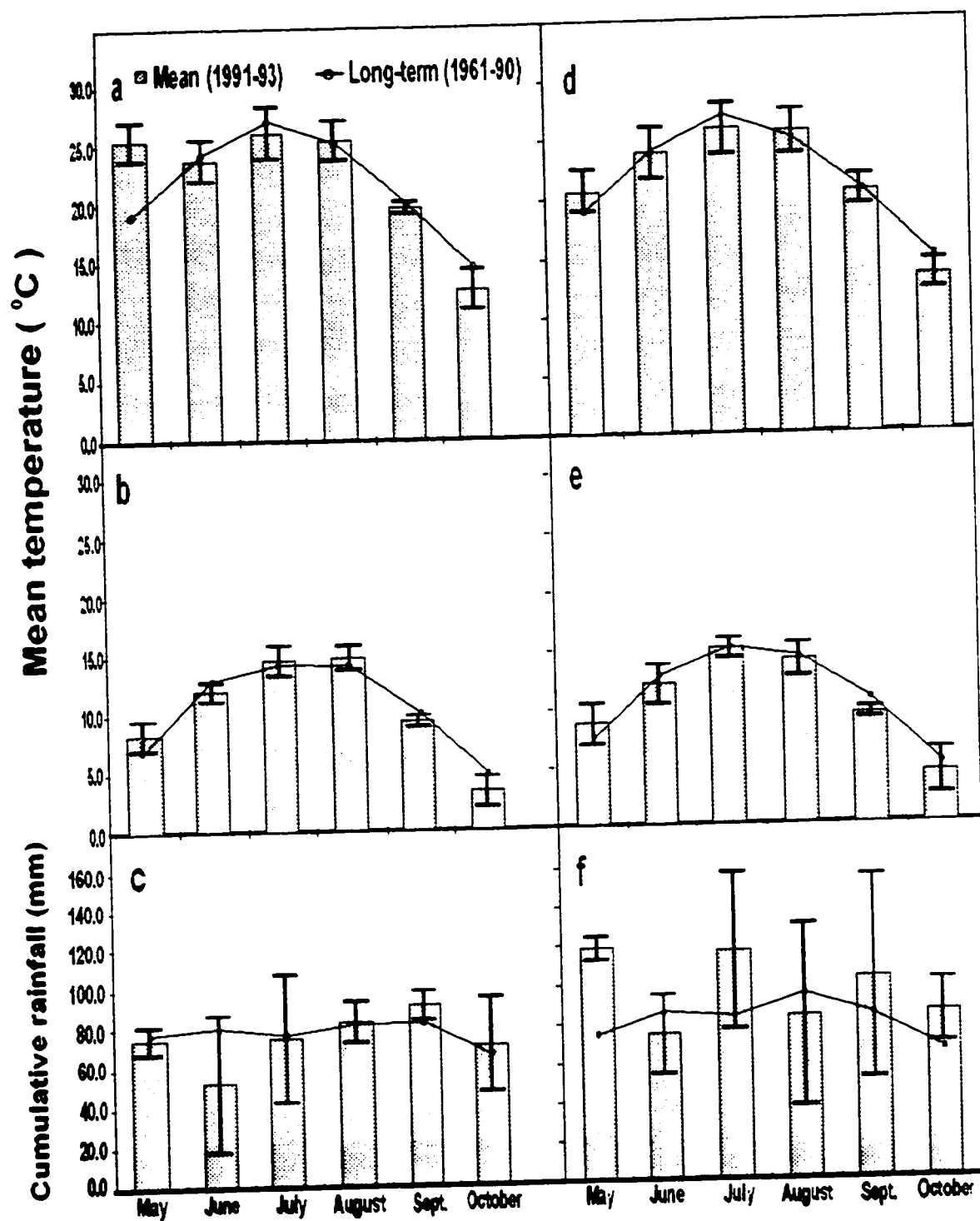


Table 2.1. Results of a 3-year survey (1991-1993) for ear mold in southwestern and east-central Ontario.

Total number of genotypes per locations	Ear mold incidence (%)	Fusarium species [§] incidence (%)						Fungal entry mode (%)			July rainfall (mm)
		gram	mon	pro	spor	sub	spp	silk	insect	bird	
South-western Ontario											
Counties surveyed in 1991: Hamilton-Wentworth, Huron, Lambton, Oxford, Perth 31 / 16	16.8	0.7	5.5	8.4	1.6	2.8	1.4	6.6	5.8	0.2	91.6
Counties surveyed in 1992: Kent, Lambton, Middlesex 5 / 4	6.3	4.6	0.0	0.0	0.0	0.0	0.0	5.0	2.9	0.0	174.7
Counties surveyed in 1993: Elgin, Huron, Kent, Lambton, Middlesex, Waterloo, Wellington 75 / 19	10.5	2.0	0.6	0.1	0.9	3.3	0.7	0.9	2.2	0.8	89.6
East-central Ontario											
Counties surveyed in 1991: Durham, Frontenac, Hastings, Lanark, Northumberland, Ottawa-Carleton 31 / 11	17.4	1.6	5.0	6.6	3.0	10.2	3.7	4.5	7.9	2.5	48.3
Counties surveyed in 1992: Durham, Northumberland 7 / 4	18.0	6.8	0.0	0.0	0.0	4.3	0.0	8.7	5.9	0.0	72.0
Counties surveyed in 1993: Northumberland 2 / 2	22.5	0.0	0.0	6.3	0.0	7.5	0.0	0.0	3.8	0.0	37.0
[§] gram= <i>F. graminearum</i> , mon= <i>F. moniliforme</i> , pro= <i>F. proliferatum</i> , spor= <i>F. sporotrichioides</i> , sub= <i>F. subglutinans</i> , spp= other minor <i>Fusarium</i> species.											

[§] gram= *F. graminearum*, mon= *F. moniliforme*, pro= *F. proliferatum*, spor= *F. sporotrichioides*, sub= *F. subglutinans*, spp= other minor *Fusarium* species.

Fusarium species comprised the majority of the isolates from the western region over the 3-year period, with respectively 93, 100 and 82% of the total fungi observed between 1991 and 1993. In the east-central region, about half of the isolates were *Fusarium* species with the other 50% consisting of other fungal species, mainly *Zygomycetes*, *Acremonium* cf. *strictum*, *Epicoccum nigrum* Link, *Gliocladium roseum* Bainier and *Alternaria alternata* spp.

The major *Fusarium* species associated with ear rot incidence throughout the survey was *F. subglutinans* followed by, *F. graminearum* and *F. moniliforme*. Considerable *Fusarium graminearum* was observed mostly in the west during the cool and wet survey of 1992 (57-100% of infected ears) and more moderately (10-30%) following the summer of 1993.

Correlations were calculated between ear rot incidence and each *Fusarium* species. A highly significant correlation coefficient was found between *F. subglutinans* and ear rot incidence over both regions ($r=0.80$, $p<0.01$, $n=56$) and to a lesser extent with *F. proliferatum* ($r=0.32$, $p<0.05$, $n=56$) over all years (Table 2.2). Secondary ear damage due to insects was positively correlated to visible symptoms of ear rot incidence ($r=0.75$, $p<0.01$, $n=56$). This is corroborated by other authors (Sutton 1982; Miller 1994). Infection through the silk channel or ear tip was also positively correlated with ear rot incidence ($r=0.37$, $p<0.01$, $n=56$).

Fusarium moniliforme, generally associated with kernel rot and *F. proliferatum*, also a probable causal agent, were both significantly correlated ($r=0.68$ and 0.69 , $p<0.01$, $n=31$) with ear rot incidence in south-western Ontario during 1991 (Table 2.3). *Fusarium graminearum*, causing agent for gibberella ear rot, was a significant factor ($r=0.56$, $p<0.01$, $n=31$) for ear rot incidence in the 1991 east-central region but to a lesser extent than *F. proliferatum* and *F. subglutinans*.

The incidence of visible ear rot varied from location to location, but was generally in the

Table 2.2. Correlation coefficients between percentages of samples with *Fusarium* specie isolates , secondary damages, ear rot incidence and July rainfall (mm) over 40-ear samples collected at all sites and years (n=56).

Variable	<i>Fusarium</i> species (%)						Fungal entry mode (%)			July rainfall (mm)
	gram [§]	mon	pro	spor	sub	spp	tip	insect	bird	
Ear rot	ns	ns	0.32*	ns	0.80**	ns	0.37**	0.75**	ns	-0.34**
Rainfall	0.45**	ns	ns	ns	-0.40**	ns	ns	ns	-0.32*	1.00

NOTES:

[§] gram= *F. graminearum*, mon= *F. moniliforme*, pro= *F. proliferatum*, spor= *F. sporotrichioides*, sub= *F. subglutinans*, spp= other minor *Fusarium* species.

ns= non significant correlation coefficient; *= significance at P=0.05; **= significance at P=0.01.

Table 2.3. Correlation coefficients between percentages of samples with *Fusarium* species isolates and ear rot incidence over all maize hybrid samples collected in southwestern and eastern Ontario in 1991-1993.

Variables		<i>Fusarium</i> species (%)					
		gram [§]	mon	pro	spor	sub	spp
Southwestern Ontario (n=107)							
1991	(30)¥	ns	0.68**	0.69**	ns	ns	ns
1992	(5)	ns	ns	ns	ns	ns	ns
1993	(72)	ns	ns	0.20*	ns	0.41**	ns
Eastern Ontario (n=39)							
1991	(31)	0.56**	0.37*	0.80**	0.46**	0.79**	0.45**
1992	(7)	ns	ns	ns	ns	0.96**	ns
1993	(1)			(Insufficient data)			

NOTES:

[§] gram= *F. graminearum*, mon= *F. moniliforme*, pro= *F. proliferatum*, spor= *F. sporotrichioides*, sub= *F. subglutinans*, spp= other minor *Fusarium* species.

() ¥ = number of samples collected in each year.

range of 10-25 percent throughout the surveys. The primary exceptions were located in south-western Ontario after the cool and wet summer in 1992, with ear rot incidences of less than 5 percent.

Other *Fusarium* spp. appear to have a minor role over the years. *Fusarium sporotrichioides* is one of them and it is possibly less pathogenic, although it shows a mycotoxicity associated with the T-2 toxin. Incidence of combined infection of a single ear involving *F. subglutinans* was high in all years, whilst *F. moniliforme* and *F. proliferatum* were the dominant species combination in 1991 (Table 2.4).

2.3.2 Environmental factors

Temperature and precipitation in the months of July, August, and early September may have a significant impact on ear rot incidence, since most infection occurs at or just after the silking stage. During these months in 1991, total rainfall was below average in both regions and temperatures were slightly above average, resulting in a hot and dry year. In 1992, rainfall was much higher than average in most months and temperatures were below average, making 1992 a cool, wet year. Of the three years, 1993 was more typical for western and east-central Ontario. July rainfall had the highest negative correlation with ear rot incidence over the two regions (Table 2.5). Total seasonal rainfall (July-September) was also correlated with ear rot ($r=-0.72$, $p<0.01$, $n=15$) over south-western Ontario data.

2.3.3 *Fusarium* species and multiple regression analysis

A stepwise regression analysis was performed using ear rot incidence as the dependent variable (Steel & Torie 1980; SAS Institute 1988). Ten independent variables were tested, including *Fusarium* species isolates, secondary damage, and ear tip infection. The best regression model based on percentage of variables incidence (S-100) for the estimation of ear rot was obtained with six independent variables that estimated 70% of ear rot observations accurately over the three-year survey ($R^2=0.70$, $P<0.01$, $n=56$), see Table 2.6.

Table 2.4. Number of isolates with a biological association between *Fusarium* species observed on plated infected kernels in 1991-1993.

<i>Fusaria</i> associations	1991	1992	1993
<i>Fusarium graminearum</i>			
gram + mon	11	0	0
gram + sub	3	2	9
gram + spp	5	0	6
gram + sub + spp	1	0	3
<i>Fusarium moniliforme</i>			
mon + pro	54	0	1
mon + sub	2	0	0
mon + spor	2	0	0
mon + spp	6	0	0
mon + pro + sub	6	0	0
<i>Fusarium proliferatum</i>			
pro + sub	8	0	5
pro + spor	4	0	0
pro + spp	4	0	0
pro + sub + spor	5	0	0
<i>Fusarium subglutinans</i>			
sub + spor	10	0	5
sub + spp	4	0	5
sub + spor + spp	4	0	1

NOTES:

§ gram= *F. graminearum*, mon= *F. moniliforme*, pro= *F. proliferatum*, spor= *F. sporotrichioides*,
sub= *F. subglutinans*, spp= other minor *Fusarium* species.

Table 2.5. Correlation coefficients between monthly rainfall and the natural log of ear rot incidence over locations (n=24) in 1991-1993.

Variables	Monthly rainfall (mm)			
	July	August	September	Total [§]
Southwestern Ontario				
Ear rot (n=15) [*]	-0.78**	-0.79**	-0.71**	-0.87**
Eastern Ontario				
Ear rot (n=9)	Non significant results			

NOTES: () ¥ = number of samples; § Total= July to September; ns= non significant correlation coefficient; * = significance at P=0.05; ** = significance at P=0.01.

Table 2.6. Ear rot incidence models according to *Fusarium* species, mode of fungal entry (silk, insect or bird wound) and July rainfall (1991-1993).

Variable	Model	± SE ^{§§}	Model	± SE
	S-100 [§]		S-3	
Intercept	7.87	2.96	-0.24	7.59
1. <i>F. graminearum</i>	0.94	0.59	7.01	3.04
2. Silk infection	0.41	0.30	5.77	2.97
3. Insect damage	0.21	0.36	4.53	3.61
4. Bird damage	-0.63E-1	0.59	2.27	3.54
5. July rainfall	-0.36E-1	0.32E-1	-0.52E-1	0.55E-1
6. (July rain* <i>F. sub</i>) ²	-0.21E-4	0.24E-4	-0.11E-2	0.65E-3
7. <i>F. subglutinans</i>	1.11	0.39	14.15	6.76
F-value	15.61**		4.11**	
R ²	0.70		0.38	
Model RMSE [†]	10.0		9.1	

[§] S-100= model based on percentage occurrence and S-3= model based on a 3-level score (used for testing on independent data); ^{§§} SE= standard error; [†] RMSE= root mean square error of the model = significant at P= 0.01.

Table 2.7. Three-level scores for *Fusarium* spp. and mode of fungal entry, and July rainfall (mm) observed on independent trials over five hybrids at three locations in 1992-1993

Location ^{ss}	Ear rot (%)	Median scores for five genotypes ^s										Cumulative July rainfall (mm)
		<i>Fusarium</i> species ^v							Fungal entry mode			
		gram	mon	pro	spor	sub	other	Silk	Insect	Bird		
1992 trials												
Stirling	10.4	0.5	0	0	0	0.5	0	0	0.5	1.0	104	
Ridgetown	14.0	0.5	0	0	0	0.5	0	0.5	1.0	0.5	114	
Arkona	6.4	1.0	0	0	0	0	0	0	0.5	0	160	
1993 trials												
Alderville	9.9	0	0.5	0.5	0.5	0.5	0	0.5	0.5	1.0	50	
Ridgetown	6.7	0	0.5	0.5	0	0.5	0.5	0	1.0	1.0	60	
Arkona	4.0	0	0	0.5	0	0.5	0	0.5	0	0	76	

^s Agri 501, Dekalb DK415, Pride K127, Pioneer 3737 (in 1992), Pioneer 3902 (in 1993), and Pioneer 3953.

^v gram= *F. graminearum*, mon= *F. moniliforme*, pro= *F. proliferatum*, spor= *F. sporotrichioides*, sub= *F. subglutinans*, spp= other minor *Fusarium* species.

^{ss} Stirling and Alderville are located in east-central Ontario, and Ridgetown and Arkona are located in south-western Ontario.

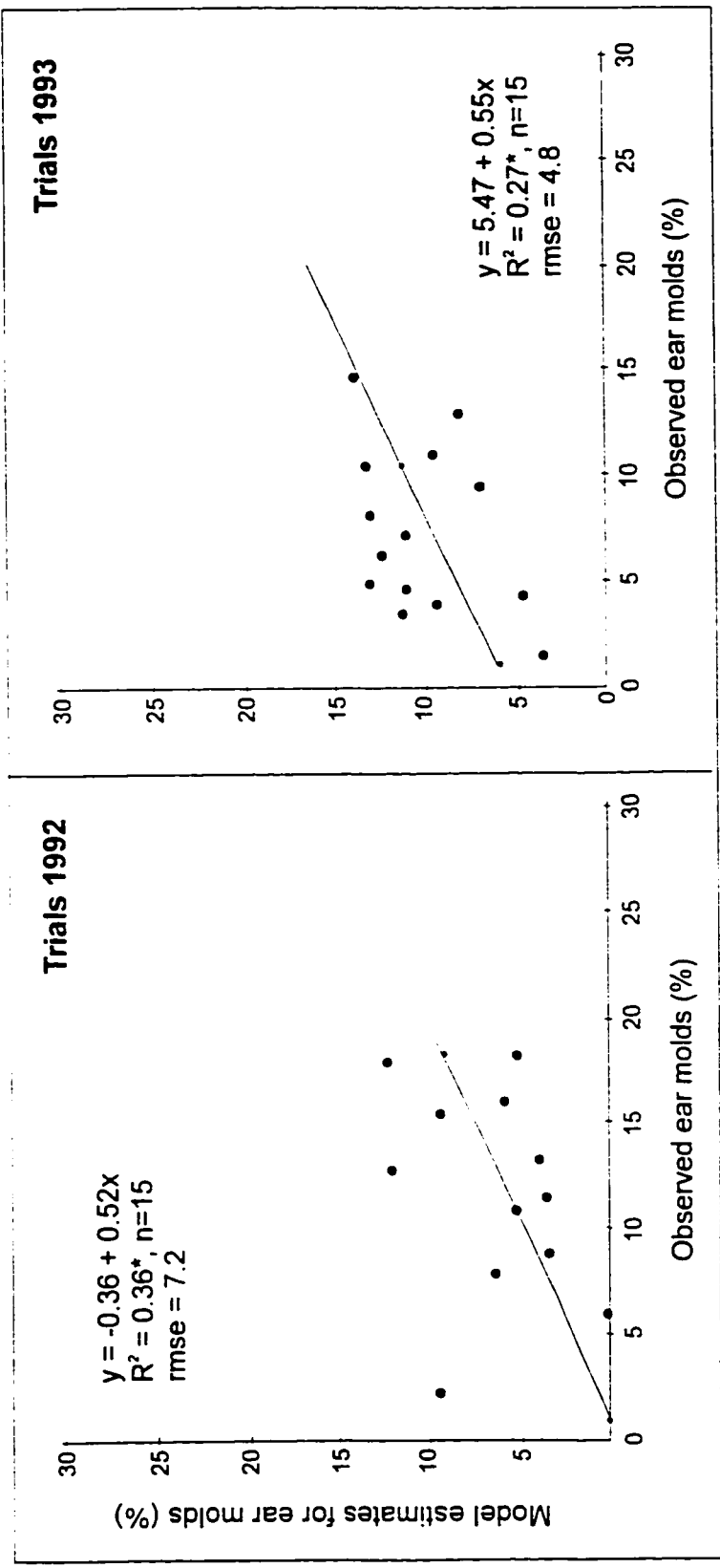
The simplified regression model (S-3) version computed on a 3-level scoring scale was less accurate but could estimate 38% of ear rot incidence observations. The scoring method used for model S-3 was comparable to the method used in independent maize hybrid trials carried out in the same regions. Model S-100 is based on the percentage of occurrence of each dependent variables for the estimation of ear rot incidence.

2.3.4 Genotypic evaluations and testing of models

Ear rot incidence ranged between 4 and 14% for five hybrids tested over two years in east-central and south-western Ontario (Table 2.7). The data collected on *Fusarium* spp., secondary damage, and ear tip infection over these trials were used in testing the models. The reliability of the S-3 model was tested based on a simple linear regression between ear rot estimates and actual ear rot observations collected on independent data consisting of three genotypic trials conducted in 1992 and 1993. Trials arranged in a completely randomized design with eight single-row replicates of 30 plants had ear rot incidence ranging between 1.0 and 18.3% over five hybrids (Agri 501, Dekalb DK 415, Pioneer 3737, Pioneer 3953, and Pride K127). The linear regressions between the S-3 model ear rot estimates (y) and observed (x) ear rot incidence gave an adequate fit over 1992 and 1993 genotypic trials (Fig. 2.2). Coefficients of determination (R^2) were significant at $P=0.05$ level for each year of the trials, with low residuals as represented by their root mean square estimate (rmse), indicating that model S-3 is useful for ear rot incidence prediction. On the other hand, we can only assume that model S-100 would have performed better because there was no independent data available with percentage incidence records for the variables used in that model.

Best results were obtained over 1993 data, with a natural log transformation of observed ear rot incidence with model S-3. The improvement with the logarithmic transformation is associated with the large variation observed among replicates in the hybrid trials. The model lack of fit found over 1992 trials is very likely related with the low level of ear rot observed that year and the absence of some major *Fusarium* species.

Fig. 2.2. Linear regressions between observed ear rot incidence (x) in genotype trials (1992-1993) and S-3 model estimates for ear rot (y) calculated from 3-level scores of *Fusarium graminearum*, *F. subglutinans*, mode of fungal entry and July rainfall. Parameters a= intercept, b= regression coefficient, R^2 = coefficient of determination, rmse= root mean square estimate for the model.



2.4 DISCUSSION

The profile of *Fusarium* species isolated from maize ears with visible signs of infection varied considerably from year to year, and varied to a lesser extent from site to site. Low epidemic levels (over 15% ear rot incidence) were only encountered in the eastern part of the survey and there were relatively few 'Hot spots' with infections above 20%. Despite the presence of other fungi, ear rot incidence was clearly associated with *Fusarium* species. *Fusarium subglutinans* appeared to be a major species associated with ear rot and was more predominant with low July rainfall conditions. *Fusarium graminearum*, the species that in the past has been mostly regarded as the principal agent of ear rot, was much less predominant than expected. This species appears to require high July rainfall and moderate temperatures.

These results are consistent with other findings on maize in eastern Canada where lower *F. graminearum* infection levels were observed during dry years (Reid et al. 1995). Also in wheat, *Fusarium* crown rot caused by *F. graminearum* is higher in wet years (Sutton 1982). Other studies done on *F. graminearum* show an association with dry weather conditions (Burgess et al. 1975; Klaasen et al. 1991). The negative effect of rainfall on ear rot incidence appeared to be associated with the major attack of *F. subglutinans* across years. The negative correlation observed between *F. subglutinans* and July rainfall is a new finding that can explain the occurrence of ear rot during dry years in eastern Canada. Background populations of *Fusarium moniliforme* and *F. proliferatum* appeared to prefer the warmer, dry years like 1991.

This indicates that even under drought conditions, ear rot incidence may be quite severe and may reach epidemic levels. The occurrence of different species in different years has a significant impact on breeding for resistance to ear rot. The data from this study have shown that it is essential that breeding programs be aimed for resistance strategy to more than one *Fusarium* species. In addition, the interaction between these species needs to be further explored.

The two major modes of infection were through secondary damage, from insect wounds on the kernels, mainly borers, and through the silk channel at the ear tip. These results are not new, but they do reinforce the need to breed for resistance to different modes of entry. The genotypic trials used for testing the models responded well at higher levels of infection. Model S-3 performed well on independent data collected over 1992-1993.

The next step involves further improvement to the predictive model and testing with data gathered in other regions. A more dynamic modeling approach is considered in current studies to improve the present model. Maize growth measurements, latent and infection duration, fungal rate of reproduction, and dispersal of *Fusarium* ascospores and macroconidia in the field should contribute to a better predictive epidemiological model for *Fusarium* ear rot.

2.5 CONCLUSION

Fusarium species are the principal agents responsible for ear rot of maize in Ontario. *Fusarium subglutinans* is the predominant species, followed by *F. moniliforme* and *F. proliferatum* in years with low rainfall and under low epidemic conditions. *Fusarium graminearum* is the predominant species in years with high rainfall. More than one species can occur on the same infected ear. The two major modes of fungal entry into maize ears are through insect wounds or by growth down the silk channel to the ear tip. These results indicate that breeding for resistance to ear rot and cultural practices aimed at controlling this disease in Ontario must also take into account the potential infection by *Fusarium* species other than *F. graminearum* and *F. moniliforme*, and the interaction between species. Also, since both silk and insect damages were significant modes of fungal entry, breeding for resistance must take into account both modes. A major finding of this study is the presence of *Fusarium subglutinans* in association with low rainfall in July. Therefore, under drought conditions, ear rot incidence may be quite severe. but the type of mycotoxins associated with *F. subglutinans* (moniliformine and beauvericin) are less toxic than the ones associated with *F. graminearum*.

CHAPTER III

GENOTYPE BY ENVIRONMENT INTERACTIONS IN GIBBERELLA EAR ROT RESISTANCE STUDIES

3.1 INTRODUCTION

Resistance mechanisms in maize against gibberella ear rot have been associated with barriers against fungal spore entry into the plant. The silk channel has been recognized as a major pathway for fungal infections (Reid et al. 1992b, 1992c). Entry into the maize ear can also be achieved through kernel wounds created by insects or birds (Sutton et al. 1980). Resistance at this level is enhanced by pericarp architecture or secondary chemicals (Assabgui et al. 1993). In addition to the loss in grain yield caused by this disease, mycotoxin contamination of infected grain is a serious concern for both human and animal health (Miller 1994).

3.1.1 Gibberella ear rot and epidemics

Earlier surveys done in Indiana during epidemic years in the early seventies have found an association between gibberella ear rot with temperature and rainfall (Tuite et al. 1974). More recent studies done in Ontario suggested that July rainfall and secondary damage, such as bird and insect damage, are important factors in the severity of fusarium ear rot (Sutton et al. 1980a; Vigier et al. 1997). Ideal disease development conditions appeared to be when temperature is lower than 23°C during the critical silking stage with nine consecutive days of rainfall (Sutton et al. 1980b). Gibberella ear rot is associated with the spread of inoculum from plant debris. *Fusarium graminearum*, the fungus that is the causal organism for this disease, is known to survive and overwinter in old plant stalks and ears of maize, stubble or debris of wheat, barley, and other cereals (Sutton 1982).

3.1.2 Approaches in plant breeding to evaluate disease resistance

Currently, plant breeders use the same basic techniques to evaluate the resistance of a particular genotype. They compare the performance of a new genotype to a known acceptable one commonly known as a 'check genotype'. This method, when conducted at different locations or environments, can help to estimate the reliability of a new genotype. Generally, genotypic reliability can be expected if the response is normally distributed across different environments, i.e. locations by years (Eskridge and Mumm 1992). However, the use of a common 'check' over many environments does not prove to be the perfect solution as environments may affect the performance of the particular reference genotype. Reliability as a performance indicator is a selection tool, but it does not explain the biological nature of genotype x environment interactions. The search for a reliable genotype can be expensive, as labor and production costs can be prohibitive when large numbers of field trials are used.

3.1.3 Genotype by environment interactions and plant resistance

Genotype by environment interactions are a major concern for the plant breeder in the development of new maize hybrids adaptable to a wide range of conditions. It is common to have a different ranking in the performance of a particular genotype across different locations and years. Genotype by environment interactions (**GE**) were first reported by Yates and Cochran (1938) in standard genotype evaluation trials. Their findings led to many different quantitative genetic studies over the years. More recently, statisticians have developed stability parameters to predict the potential variation of a particular genotype in different environments (Freeman 1973; Mather and Caligari 1974; Westcott 1986; Lin and Binns 1988).

In the domain of field experimentation and plant breeding for disease resistance, the variability of resistance components between different environments is sometimes difficult to distinguish. This is because the level of host resistance to a particular disease can vary in different environments due to weather conditions that may favor or hinder the development of a particular disease.

3.1.3.1 Stability analysis adaptations

Stability analysis is a method used in the past by plant breeders to select the best material based mostly on yields obtained across a range of environments. This approach has not been used a great deal in host resistance breeding programs (Snijders and Van Eeuwijk 1991). Current statistical methods to establish genotype adaptability or stability across environments need to be improved. Some new approaches developed recently may be more successful than methods that have been reported over the past 30 years (Baker 1996). Stability analysis has evolved in recent years, and a different terminology is being accepted among researchers. The term stability has been quoted and misquoted in the literature and some authors have suggested restricting its use in reference to the response of a genotype over different years, which is a part of the interaction that is not predictable. The term 'adaptability' should refer to the response of a genotype to differences between locations that are more predictable (Lin and Binns 1994). The same authors reported that a lack of information also exists concerning the nature and causes of interactions between genotypes and environments despite their importance.

3.2 Approaches for genotype by environment interaction

Large genotype-environment interactions can slow down the progress of genotype selection, since it is difficult to show the superiority of a cultivar or hybrid plant through statistical evidence. One of the first attempts to correct this pitfall was achieved by using a statistical analysis called the Joint Regression Model (Yates and Cochran 1938). This method remained popular for over thirty years since Finlay and Wilkinson applied the Yates and Cochran method to the analysis of barley adaptability and their approach was followed by other authors (Finlay and Wilkinson 1963; Eberhart and Russell 1966; Westcott 1986).

3.2.1 The linear and non-linear models

Recent reviews (Lin and Binns 1991; Gauch 1992; Lin and Binns 1994; Baker 1996) have shown that two basic statistical methods have been popular to analyze genotype x environment interactions during the eighties. They are: the additive linear model ANOVA

which assumes that GE interactions and environmental effects are both random variables.

3.2.1.1 The joint regression model

The joint regression model is based on linear regression analysis where a genotype deviation is tested against an 'environmental index' or a stability factor which is in most cases simply the overall mean of a variable calculated for a group of genotypes tested at a particular location and year called also 'environment'. Yield stability is observed when the slope of the regression line, or the regression coefficient, is equal to 1 and the total variance deviation for all the tested genotypes is minimal (near 0). Stable disease resistance across environments is achieved when the slope of the genotype regression line is near 0 ($0 < b < 1$).

Variations based on this model have been reviewed earlier by Lin et al. (1986) from its conception in 1938. Their critique led to a conclusion, largely quoted in the literature, concerning the lack of fit of the joint regression analysis and the need for new approaches (Lin et al. 1986; Lin and Binns 1988, 1994).

3.2.1.2 The additive main effects and multiplicative interactions model

In the 1990s, new methods have been investigated to evaluate genotypic stability in an attempt to learn more about the biological causes of interactions rather than only their particular consequences. Gauch (1992) and colleagues popularized a two-way genotype by environment analysis using the analysis of variance additive main effects combined with multiplicative interactions (**AMMI**) rather than the usual ANOVA using only additive terms. This approach results in a reduction of terms to be analyzed using multiplicative components expressed by principal component analysis (PCA). The procedure helps also to visualize the interactions with the use of biplot diagrams which represent the interactions.

In large data sets from trials undertaken around the world and compiled by the International Maize and Wheat Improvement Centre (CIMMYT), it was found that AMMI

analysis gave more precise estimates of genotypic yields across locations compared to the means across replicates technique, by allowing clustering in subsets of positive interactions with high stable genotypic performance (Crossa *et al.* 1991).

3.2.3 Objectives and hypothesis

It is hypothesized that the resistance of maize silks to *Fusarium graminearum* infection identified in the inbred line CO272 and the kernel resistance of inbred line CO325 are always expressed independently of external environmental conditions. This hypothesis suggests that a physical resistance exists in the silks, based on the presence of cuticular waxes which are likely to be stable over many environments (Reid *et al.* 1992a, 1992b, 1994). Physical resistance is possible at the kernel level against ear rot that may be associated with the presence of several genes (Chiang *et al.* 1987; Chungu *et al.* 1996). In any case, the stability or plasticity of these two modes of resistance must be established if these genotypes are to be successfully used to develop maize hybrid with improved resistance.

The present approach has never been attempted and its originality relies in incorporating the analysis of the genotypic resistance with the use of a visual disease rating. The partitioning of the genotype by environment interactions in the statistical analysis should allow the identification of the source of the interaction associated with the variation in plant resistance across different environments.

The objective of the present study is to compare the Joint regression and the AMMI models to explain the importance of GE interaction for nine genotypes evaluated for their resistance against gibberella ear rot with two inoculation methods. Genotype by environment interactions are not only measured, but their source is investigated using weather characteristics taken at critical plant growth stages.

3.3 MATERIALS AND METHODS

The data used in this study were taken from a total of 17 field trials performed from

1994 to 1996 across east-central Ontario and south-western Québec.

3.3.1 Field protocol

A selection of susceptible and moderately resistant genotypes were tested at five locations in 1994 (Ottawa, Nepean, Cobden, Prescott, and Winchester) with an additional location in both 1995 and 1996 in St-Polycarpe, Québec. Each field lay-out consisted of two contiguous trials: one for the inbred lines and another for hybrid maize genotypes. Trials were set up as randomized complete block design with four blocks. Plots consisted of one row of 25-30 plants which were inoculated with a macroconidial suspension of three *F. graminearum* strains (DAOM194276, DAOM180378, and DAOM21678) obtained from the National Agriculture and Agri-Food Canada Fungus Cultures Collection as prepared by Reid *et al.* (1992b). Inoculation methods consisted of a silk-channel injection and a kernel-stab wound (Reid *et al.* 1992b; Chungu *et al.* 1996; Reid *et al.* 1996b). Controls consisted of one uninoculated row for background infection and a half-row inoculated with sterile water injected with either the silk-channel and kernel-stab wound methods .

The inbred lines used in this study consisted of susceptible gibberella ear rot lines CO266 and CO265 and moderately resistant lines CO272 and CO325; susceptible commercial hybrids were Dekalb 415, Pioneer 3953 and Pioneer 3902, moderately resistant hybrids were Funks G4106 and Pride K127. The inter- and intra-row spacings were 0.75 m and 0.20 m, respectively, to achieve a planting density of 66,500 plants per ha similar to commercial production. Critical growth stages such as the young silking stage and mature silking stage were recorded for best inoculation timing. Weather variables such as rainfall, air temperature and relative humidity were recorded at each site on a daily basis between July and September.

The silk channel inoculation was used to simulate a fungal infection down the silks towards the maize kernels and the kernel-stab wound inoculation was applied to simulate a fungal attack through kernel wounds inflicted by birds or insects. Timing of inoculation for both silk channel and kernel-stab wound techniques were done accordingly to the

maturity of each genotype as described by Reid *et al.* (1996b); early silking stage (4-6 days) was the ideal time for silk channel inoculation and mature silking occurring later was the best time for kernel-stab wound inoculation.

Visual ratings to assess ear rot severity were done near harvest in late September following a 1 to 7 rating scale (Fig. 3.1). The ear rot rating scale is based on the percentage of visibly infected maize kernels (Bolton *et al.* 1990; Reid *et al.* 1996b). Maize ears were harvested at normal grain harvesting moisture in the range of 20-30% and shelled to obtain dry kernel weight. The number of primary ears harvested by hand in October ranged generally from 3 to 10 ears for inbred lines and 10 to 15 ears per replicate for hybrids. Replicates with less than three ears were not harvested and were recorded as missing data.

3.3.2 Data analyses

A standard analysis of variance was done using the general linear model (GLM) to calculate the least square means over replicates and treatments as data was unbalanced due to missing data (Steel and Torrie 1980; SAS Institute Inc. 1988). Missing data occurred in Environments 13, 14, 15, 16 and 17 on inbred line CO272, due to lack of available seeds resulting in three out of four replicates being planted.

Treatment effects and interactions between genotypes and inoculation methods were calculated to assess the effects of inoculation on visual ear rot and ear dry weight compared to control treatments. The total data set was then analyzed by inoculation technique for genotype x environment interactions.

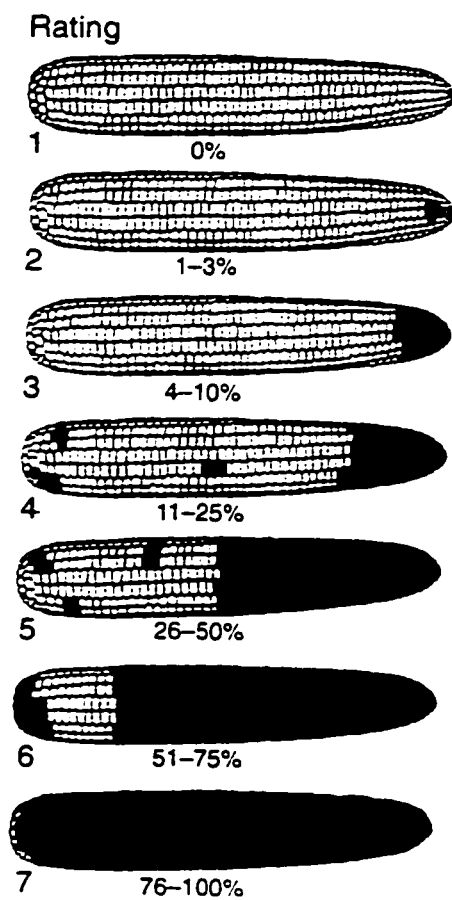
3.3.2.1 Rank difference tests

Ranking the best genotypes from low to high performance according to visual ear rot and dry weight was the first attempt to select the genotypes with the best disease resistance across environments and best yield factor performers. A way to remove bias is to compare a genotype mean to the maximum mean observed at a particular location or

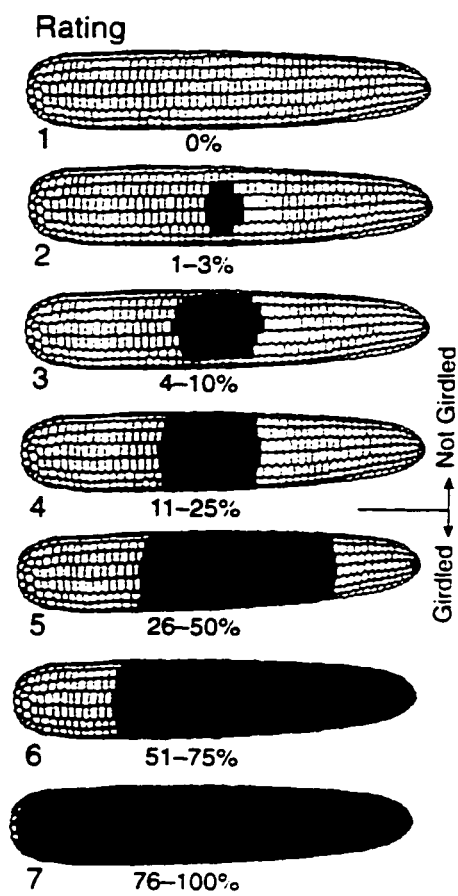
Fig. 3.1. Ear rot rating scale

Disease severity rating scales and percentage of visibly infected kernels for gibberella ear rot after silk channel (A) and kernel (B) inoculations with *Fusarium graminearum*. (Reid et al. 1996)

(A) Silk Channel



(B) Kernel



environment. Lin and Binns (1988b) have developed a method to rank genotypes according to a genotype x environment statistic they developed to detect a superior genotype.

3.3.2.2 Joint regression model

In the joint regression model, the GE interaction sum of squares is divided in two parts: one part representing the heterogeneity of the linear regression coefficients and the other part showing the pooled deviations from each genotype's individual regression line or the variation due to the unexplained deviation from the regression on an environmental index (Finlay and Wilkinson 1963; Eberhart and Russell 1966; Westcott 1986; Zobel *et al.* 1988; Baker 1996).

The basic statistical model for the joint regression analysis is:

$$Y[ijk] = \mu + e[i] + r[ik] + g[j] + b[j]*e[i] + d[ij] + w[ijk]$$

where:

$Y[ijk]$ is an individual observation in the i environment for the j genotype in the k environment,

μ is the grand mean over all field trials,

$e[i]$ is the effect of environment i ,

$r[ik]$ is the effect of replication k in environment i ,

$g[j]$ is the effect of genotype j ,

$b[j]$ is the linear regression coefficient for genotype j ,

$d[ij]$ is the deviation from regression for genotype j in environment i , and

$w[ijk]$ is the random effect associated with a test plot.

A standard additive analysis of variance was computed followed by the calculations of genotype means across environments and environmental means across genotypes using PROC GLM (SAS Institute 1988). The last calculations used PROC REG to compute the

individual linear regressions for each genotype under study across each environment.

The genotype performance was rated according to Eberhart and Russell (1966) stability parameters. According to these authors, the environment index (E linear) is considered to be constant with one degree of freedom and they use the analysis of covariance methodology between interactions and environmental effects. The environmental index represents the mean results obtained over a group of genotypes at a particular environment. The graphical representation used by Eberhart and Russell shows the regression lines with *x* values showing the environmental index of a particular genotypic measure and *y* values representing the actual measures of a genotype in each environment.

3.3.2.3 The Additive Main and Multiplicative Interaction (AMMI)

AMMI is a two-factor analysis of variance (genotypes and environments) followed by singular value decomposition of the residuals to partition the interaction into multiplicative effects (Zobel and Wallace 1995). Singular value deviations are also called principal component analysis (PCA). The expression of the interactions between genotypes and environments is dealt with differently in the AMMI model compared to the joint regression model. This stability model expresses interactions as a sum of multiplicative effects. The difference between the two models lies here: AMMI is a multiplicative model and the joint regression model is an additive one.

The model comparisons presented here for the AMMI model use the PC-based AgroBase™ program, according to the Zobel approach (Zobel *et al.* 1988). The AMMI analysis partitions the interactions into separate axes according to the pattern of interaction between the levels of factors (Zobel and Wallace 1995). The model computes the percentage of the variance or the contribution to the GE interactions. These scores are graphically charted on a biplot to give a visual interpretation of the interaction (AgroBase™ 1996). Stable genotypes are closer to the abscissa axis.

The model used by AMMI is:

$$Y_{[ijk]} = \mu + e_{[i]} + r_{[ik]} + g_{[j]} + S(d_{[l]}*r_{[il]}*c_{[jl]}) + w_{[ijk]}$$

where:

$S(d_{[l]}*r_{[il]}*c_{[jl]})$ replaces the $b_{[j]}*e_{[i]} + d_{[ij]}$ components used in the additive model for the joint regression model,

$d_{[l]}$ is the common multiplier for set l of multiplicative interaction terms,

S is the summation over subscript l ,

$r_{[il]}$ is a score for environment i in set l of multiplicative interaction terms, and

$c_{[jl]}$ is a score for genotype j in set l of multiplicative interaction terms.

3.3.2.4 Weather variables and GE interactions

Weather variables for each environment were derived from meteorological records collected at each site during critical developmental stages from July to September. Daily records were taken during the vegetative stage in July, the young and maturing silking stages in August and ear fill period in September. A total of 15 out of 17 environments had weather records on site. Trials in Nepean at the Central Experimental Farm were matched with the same weather records collected at the Ottawa site, located 8 km away. All trials were within a 200-km radius of Ottawa to the east or south-west.

Daily records during the July-September period consisted of mean hourly temperatures, relative humidity, and cumulative rainfall. They were recorded and transformed into three monthly weather variables: the number of days with temperatures below 21° C, the number of days with a relative humidity over 80%, and the cumulative rainfall in mm.

In an attempt to estimate the effect of weather variables on gibberella ear rot rating, the three weather variables identified earlier were correlated with genotype ear rot ratings. Most significant weather variables are then used as covariates in an analysis of covariance to measure their contribution at explaining genotype by environment interactions.

3.4 RESULTS AND DISCUSSION

3.4.1 Weather variables

Monthly weather variables during the growing season were calculated for all locations and years, except for Prescott which only had partial results due to equipment malfunction (Table 3.1). The most extreme weather variables were found in Winchester (ENV-5 and ENV-10) and Cobden (ENV-3 and ENV-8) in 1994 and 1995. Winchester, located 75 km south-east of Ottawa, was dry during both years with the lowest number of days with high relative humidity (39 days), the lowest number of cool days (6 days) in July, and the lowest cumulated rainfall in both July and August (64mm) in 1994. In Cobden, situated 120 km, west of Ottawa, was more humid in 1994 and 1995, with the highest number of days with high relative humidity (73 days), an average number of cool days (13 days), and high rainfall in July (143 mm) of 1994.

Similar patterns were found in 1995 at both locations with low rainfall in July and August (96 mm) and high relative humidity in September (25 days) in Winchester compared to high rainfall (250 mm) and average relative humidity (18 days) for the same period in Cobden. Trials in 1996 were characterized across all locations by high rainfall in July and September with a dry interval in August.

3.4.2 Analysis of variance across inoculation treatments

A first analysis of variance was done for each genotype sub-groups, i.e. inbred lines and hybrids to calculate means, standard deviation, expressed as coefficient of variation (CV) percentages (standard deviation/mean) and significance of mean differences among each genotype sub-group. A separate ANOVA was performed for silk channel and kernel-stab inoculation methods and natural infection.

Table 3.1. Ranges of environmental variables during vegetative stage (July), silking stage (August) and ear fill stage (August to September).

Code	Location	Number of days with Rel. hum. > 80%			Number of wet and cool days*			Monthly rainfall (mm)		
		July	Aug.	Sept.	July	Aug.	Sept.	July	Aug.	Sept.
Trials in 1994										
ENV 1	Ottawa	23	20	20	14	13	15	92	112	59
ENV 2	Nepean	23	20	20	14	13	15	92	112	59
ENV 3	Cobden	20	27	26	13	13	14	143	72	50
ENV 4	Prescott	--	--	--	--	--	--	--	--	--
ENV 5	Winchester**	8	15	16	6	13	14	18	46	49
Trials in 1995										
ENV 6	Ottawa	14	16	19	23	14	15	104	84	43
ENV 7	Nepean	14	16	19	23	14	15	104	84	43
ENV 8	Cobden	18	17	25	15	8	15	121	129	55
ENV 9	Prescott	--	--	--	14	12	10	80	113	56
ENV 10	Winchester**	10	21	18	5	3	2	58	38	--
ENV 11	St-Polycarpe	23	19	16	18	6	6	156	52	26
Trials in 1996										
ENV 12	Ottawa	--	--	--	19	9	8	149	87	74
ENV 13	Nepean	--	--	--	19	9	8	149	87	74
ENV 14	Cobden	14	22	15	14	7	13	83	63	112
ENV 15	Prescott	--	--	--	12	9	15	71	77	144
ENV 16	Winchester	16	25	24	13	9	15	95	77	134
ENV 17	St-Polycarpe	18	10	21	11	7	14	136	30	149

* Number of consecutive days with minimum temperature below or equal to 21 degrees Celcius with rainfall.

** Data starting on July 15; (-) no data available due to equipment malfunction.

3.4.2.1 Effect of gibberella ear rot on genotypes

The ANOVA analysis results show a significantly higher ear rot rating with the kernel inoculation technique compared to the silk channel method (Tables 3.2 and 3.3). The silk channel technique had generally higher coefficients of variation percentages (CV) across environments ranging from 9 to 57% with lower visual ear rot ratings in the range of 1.8 to 3.4 compared to the kernel-stab inoculated maize ears with a CV between 3 and 36 and ratings from 2.9 to 5.6. Control plots under natural infection pressure had low ratings in the range of 1.17 to 1.62 which are considered to be minimal. The same type of analysis performed on mean dry weight over the 17 environments reveals the expected lower yields with the inbred line sub-groupings compared to maize hybrid due to the heterosis effect (Tables 3.4 and 3.5).

Higher levels of infection obtained with the kernel-stab inoculation can be explained by the invasive nature of stabbing kernels and exposing their damaged pericarp to fungal infection especially in inbred lines which have smaller ears and a higher infection area per total ear comparatively with larger ears found with hybrids. These hybrids also have another advantage due to their increased ear height above the ground, which is about twice the height of the short inbred lines making them less susceptible to secondary infections from rain splashing on maize leaves and silks.

Inoculation techniques had a significant effect on all genotypes' ear rot ratings compared to control treatments which had lower infection levels (Table 3.6a). The kernel stabbing technique gave significantly higher visual ear rot ratings in both inbred and hybrid groups compared to the silk channel method in all the trials except for ENV-17. Visual ratings were also similar among control methods, excepted for the kernel-stab control which tended to give higher ratings than the other control methods most likely because of the secondary damage done to the kernels. Dry weight across inoculation treatments were significantly lower with the kernel-stab inoculation technique in only ENV-3, ENV-7, and ENV-8 for the inbred group, and ENV-1, ENV-4, ENV-5, and ENV-7 for the hybrid group (Table 3.6b).

Table 3.2. Ear rot ratings of nine genotypes across 17 environments and three years using the silk channel inoculation technique

Genotypes	1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994 1994															
	ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	ENV-7	ENV-8	ENV-9	ENV-10	ENV-11	ENV-12	ENV-13	ENV-14	ENV-15	ENV-16
Inbred group																
CO272	1.1	1.9	1.7	1.9	1.6	1.5	1.7	2.1	1.6	2.3	1.7	1.6	3.7	3.1	1.9	1.6
CO325	1.1	1.5	2.0	1.7	1.3	1.2	1.4	2.2	1.1	4.2	2.3	1.4	1.5	2.0	1.7	1.3
CO266	3.1	3.9	5.2	3.9	3.8	2.7	4.0	5.1	3.5	1.7	4.8	2.9	3.5	4.6	3.9	2.9
CO265	2.4	2.0	4.0	2.7	1.4	1.9	2.3	4.4	1.9	1.3	2.4	2.0	3.8	3.4	2.7	2.5
Mean	1.9	2.5	3.2	2.6	2.1	1.8	2.4	3.4	2.0	2.4	2.8	2.0	3.1	3.2	2.6	2.0
P	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.03	0.01	0.01	0.01
C.V. %	23	21	16	13	23	23	34	9	12	23	19	24	24	13	13	18
Hybrid group																
Pioneer 3953	1.5	2.3	2.7	2.0	2.9	1.5	1.8	1.5	1.9	1.8	1.6	2.6	2.3	4.5	2.0	2.3
Pioneer 3902	1.6	3.5	4.1	2.7	1.4	2.4	2.8	3.2	3.8	1.3	2.1	4.4	4.0	5.4	2.7	2.9
Pride K127	1.6	1.4	2.0	2.1	2.1	1.6	1.7	1.6	2.1	1.4	1.2	1.8	1.6	3.1	2.1	1.8
Dekalb 415	2.3	3.5	3.2	3.7	2.1	2.0	1.7	1.8	2.1	1.9	3.8	2.0	2.4	3.1	3.7	4.3
Ciba G4106	1.2	1.4	1.4	1.8	1.1	1.8	1.6	1.6	1.5	1.5	2.6	1.2	1.6	1.4	1.8	1.5
Mean	1.7	2.4	--	2.4	1.9	1.9	2.0	2.0	2.3	1.6	2.3	2.4	2.4	3.5	2.4	2.6
P	0.03	0.01	--	0.01	0.01	0.21	0.01	0.01	0.19	0.18	0.01	0.01	0.01	0.01	0.01	0.01
C.V. %	23	26	--	20	23	29	17	13	57	24	22	23	18	14	20	14

(--) adjusted means not computed because too many missing data
Rating scale from 1 to 7.

Table 3.4. Dry grain weight in grams of nine genotypes across 17 environments and three years using the silk channel inoculation technique

Genotypes	1994	1994	1994	1994	1994	1994	1995	1995	1995	1995	1995	1995	1996	1996	1996	1996	1996
	ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	ENV-7	ENV-8	ENV-9	ENV-10	ENV-11	ENV-12	ENV-13	ENV-14	ENV-15	ENV-16	ENV-17
Inbred group																	
CO272	15.18	7.58	1.95	25.72	12.93	17.55	34.64	21.49	18.68	17.93	18.4	13.04	--	--	9.14	--	--
CO325	51.58	48.2	28.13	47.93	43.43	18.02	35.25	35.32	25.51	23.46	51.18	36.34	42.61	33.08	31.4	33.53	30.13
CO266	41.82	34.74	32.51	39.39	35.82	21.48	21.86	23.08	21.46	10.81	29.33	28.78	43.56	33.17	78.07	35.15	62.88
CO265	36.91	23.42	15.63	31.34	21.78	39.87	50.5	42.07	40.48	39.36	26.45	32.23	--	34.87	29.44	52.48	49.1
Mean	35.93	27.83	21.14	35.32	28.49	24.23	37.52	31.74	26.53	25.14	32.71	29.25	--	33.37	37.35	37.11	--
P	0.01	0.01	0.09	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.53	--	0.98	0.02	0.57	--
C.V. %	18	21	66	18	9	29	17	12	29	13	16	54	--	43	11	64	--
Hybrid group																	
Pioneer 3953	105.6	96.08	44.62	106.04	86.11	86.28	82.71	82.82	78.48	87.12	102.93	133.39	109.75	54.71	92.09	104.71	109.27
Pioneer 3902	113.86	89.85	25.79	97.33	69.65	73.2	87.54	93.42	117.94	109.54	109.5	117.75	130.23	76.42	110.41	116.48	113.59
Pride K127	99.28	100.07	62.18	94.88	90.38	60.44	88.17	87.95	62.07	92.74	105.2	96.24	81.69	82.35	99.89	119.03	74.02
Dekalb 415	119.06	78.06	--	110.6	80.93	83.24	94.56	83.01	67.01	87.76	90.75	97.27	112.62	66.33	82.13	96.16	96.17
Ciba G4106	108.66	102.98	40.62	103.77	101.42	64.36	95.07	86.51	66.98	98.18	117.88	111.3	114.89	93.74	97.07	136.26	108.81
Mean	110.76	93.41	41.94	102.52	87.03	73.51	90.23	86.84	78.5	95.59	105.25	110.11	108.91	74.1	96.69	113.65	100.37
P	0.57	0.02	0.07	0.16	0.16	0.05	0.43	0.25	0.01	0.19	0.24	0.1	0.17	0.14	0.7	0.16	0.54
C.V. %	12	10	32	9	16	17	11	8	22	13	15	16	23	26	27	17	36

(--) adjusted means not computed because too many missing data

Table 3.5. Dry grain weight in grams of nine genotypes across 17 environments and three years with kernel inoculation

Genotypes	ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	ENV-7	ENV-8	ENV-9	ENV-10	ENV-11	ENV-12	ENV-13	ENV-14	ENV-15	ENV-16	ENV-17
Inbred group																	
CO272	5.8	9.55	3.64	13.84	18.85	15.82	28.98	28.71	15.01	10.28	30.3	11.86	--	--	--	44.05	19.27
CO325	52.17	50.29	20.96	39.8	0	25.03	31.42	27.51	30.43	20.48	49.15	47.93	17.41	37.63	34.69	49.65	62.72
CO266	33.92	20.42	13.52	49.17	22.28	15.46	19.95	19.37	14.97	16.67	32.6	27.7	31.59	31.31	35.51	35.94	12.19
CO265	33.67	17.22	10.76	23.48	23.21	41.49	45.71	41.27	49.48	42.62	25.77	22.19	--	--	14.86	34.83	74.28
Mean	35.35	24.37	12.22	26.97	25.27	24.45	31.52	29.83	27.47	23.69	35.83	30.76	20.72	32.43	33.86	42.67	53.36
P	0.01	0.01	0.01	0.02	0.07	0.01	0.01	0.01	0.01	0.04	0.01	0.01	--	--	0.3	0.43	0.33
C.V. %	19	15	23	28	19	12	13	11	21	33	8	18	--	--	15	23	67
Hybrid group																	
Pioneer 3953	63.89	76.97	31.35	65.2	64.77	70.38	71.92	76.13	86.48	86.16	85.45	93.84	113.45	82.56	102.67	106.79	67.78
Pioneer 3902	90.09	98.66	23.92	86.4	87	89.69	84.57	102.4	102.16	104.97	111.85	98.07	120	82.56	95.28	110.26	105.39
Pride K127	107.2	84.42	45.05	86.18	83.62	73.91	82.37	78.91	87.75	94.31	92.68	78.83	93.81	50.45	70.53	86.32	73.61
Dekalb 415	98.94	65.58	--	67.75	67.58	85.91	72.57	87.77	80.78	91.08	112.3	107.03	98.78	61.67	108.61	91.71	84.15
Ciba G4106	93.92	111.46	44.36	91.36	79.66	61.19	79.36	83.13	75.87	71.59	98.88	106.65	93.43	89.52	120.96	122.57	92.68
Mean	90.81	87.42	34.54	79.38	76.53	76.92	78.16	85.67	86.61	90.88	100.23	98.16	104.63	73.35	100.91	103.53	84.79
P	0.14	0.12	0.01	0.01	0.05	0.06	0.75	0.01	0.38	0.22	0.04	0.35	0.75	0.34	0.52	0.44	0.59
C.V. %	25	27	15	11	14	16	21	9	21	19	12	19	32	27	40	28	42

(- -) adjusted means not computed because too many missing data

Table 3.6a. Analysis of variance and multiple comparisons of ear rot ratings between silk channel inoculation , kernel-stab inoculation , and silk channel control , kernel-stab control , and background natural infection across 17 environments.

		ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	ENV-7	ENV-8	ENV-9	ENV-10	ENV-11	ENV-12	ENV-13	ENV-14	ENV-15	ENV-16	ENV-17
		Ear rot ratings																
Inbred group	Silk channel	1.9 c	2.4 b	3.2 b	2.6 b	2.1 b	1.8 b	2.4 b	3.4 b	2.0 c	2.4 b	2.8 b	2.0 b	3.1 b	3.2 b	2.6 b	2.0 b	2.9 a
	Kernel-stab	4.5 a	4.4 a	5.6 a	3.1 a	4.7 a	3.9 a	4.1 a	4.7 a	4.3 a	3.9 a	4.1 a	2.9 a	4.4 a	5.5 a	3.1 a	3.0 a	3.1 a
	Silk channel control	1.5 d	1.8 c	1.8 d	1.6 d	1.6 c	1.1 c	1.4 c	1.6 d	1.3 d	1.3 c	1.5 c	1.3 d	1.4 c	1.8 d	1.6 d	1.9 bc	1.7 c
	Kernel-stab control	2.4 b	2.3 b	2.7 c	2.0 c	2.0 b	2.0 b	2.3 b	2.8 c	2.5 b	2.1 b	2.6 b	1.7 c	1.6 c	2.6 c	2.0 c	1.9 b	2.1 b
	Natural	1.4 d	1.8 c	1.8 d	1.3 d	1.6 c	1.1 c	1.5 c	1.7 d	1.5 d	1.3 c	1.6 c	1.2 d	1.5 c	1.4 e	1.3 d	1.4 c	1.7 c
	Mean	2.3	2.5	3.0	2.1	2.4	2.0	2.4	2.8	2.3	2.2	2.5	2.5	1.8	2.5	2.1	2.1	2.3
P		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C.V. %	0.2	0.2	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.4	0.1	0.2	0.3
Hybrid group	Silk channel	1.7 b	2.4 b	3.0 2.4 b	1.9 b	1.9 b	1.8	2.0 b	2.0 b	2.3 b	1.6 b	2.3 b	2.4 b	2.4 b	3.5 a	2.4 b	2.6 b	3.3 a
	Kernel-stab	3.6 a	3.6 a	4.2 3.2 a	3.6 a	3.1 a	3.5 a	4.0 a	4.0 a	3.5 a	3.6 a	3.4 a	3.6 a	2.8 a	3.8 a	3.2 a	3.4 a	3.0 b
	Silk channel control	1.1 c	1.2 c	1.6 1.3 c	1.2 c	1.1 c	1.1 c	1.3 d	1.3 d	1.1 c	1.1 c	1.4 cd	1.2 c	1.3 c	2.0 b	1.3 c	1.4 d	1.5 d
	Kernel-stab control	1.2 c	1.2 c	1.8 2.3 b	1.3 c	1.7 b	1.2 c	1.7 c	1.7 c	1.5 c	1.3 c	1.5 c	1.4 c	1.3 c	1.9 b	2.3 b	1.7 c	1.9 c
	Natural	1.1 c	1.1 c	1.2 1.4 c	1.0 c	1.1 c	1.1 c	1.2 d	1.2 d	1.1 c	1.1 c	1.2 d	1.2 c	1.2 c	1.6 c	1.4 c	1.2 d	1.4 d
	Mean	1.7	1.9	2.4	2.1	1.8	1.8	1.8	2.0	1.9	1.7	2.0	1.9	1.8	2.6	2.1	2.1	2.2
P		0.001	0.001	---	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
	C.V. %	0.1	0.2	0.3	0.2	0.3	0.2	0.2	0.2	0.1	0.3	0.2	0.2	0.2	0.2	0.2	0.2	0.2

C.V.% = coefficient of variability or (standard deviation / mean)*100

Same letters across treatment for each environment were not different at the 0.01 level of probability; (---) data available on only one replicate.

Table 3.6b. Analysis of variance and multiple comparisons of dry weight between silk channel inoculation, kernel-stab inoculation, and silk channel control, kernel-stab control, and background natural infection across 17 environments.

	ENV-1	ENV-2	ENV-3	ENV-4	ENV-5	ENV-6	ENV-7	ENV-8	ENV-9	ENV-10	ENV-11	ENV-12	ENV-13	ENV-14	ENV-15	ENV-16	ENV-17
Dry grain weight (g/ear)																	
Inbred group																	
Silk channel	35.9	27.8	21.1 a	35.3	28.5	24.2	37.5 a	31.7 b	26.5	25.1	32.7	29.2	48.1	33.4	37.4	37.1	47.6
Kernel-stab	35.4	24.4	12.2 b	27.0	25.3	24.5	31.5 b	29.8 b	27.5	23.7	35.8	30.8	20.7	32.4	33.9	42.7	53.4
Silk channel control	44.0	20.6	19.6 a	39.2	26.8	24.5	37.5 a	37.3 a	35.3	29.5	39.7	43.0	83.0	41.0	49.7	44.6	55.9
Kernel-stab control	40.8	24.4	21.7 a	34.0	31.1	25.0	40.2 a	35.4 a	23.5	32.6	42.0	42.5	107.0	41.3	31.6	36.1	65.8
Natural	37.0	35.2	21.5 a	35.7	24.9	28.8	39.8 a	37.4 a	29.0	25.9	35.6	41.2	54.8	46.5	43.8	57.4	61.0
Mean	38.4	26.7	18.9	34	27.2	25.4	37.3	34.4	27.9	27.0	37.0	37.1	55.9	39.7	40.9	44.7	57.3
P	0.061	0.19	0.043	0.154	0.09	0.25	0.001	0.001	0.404	0.461	0.21	0.111	0.065	0.475	0.581	0.38	0.797
C.V. %	0.22	0.6	0.42	0.2	0.19	0.27	0.15	0.11	0.25	0.24	0.17	0.44	0.31	0.56	0.6	0.56	0.61
Hybrid group																	
Silk channel	110.8 a	93.4	bc 41.9	102.5 a	87.0 b	73.5	90.2 a	86.8 bc	78.5	95.6	at 105.3 bc	110.1	108.9	74.1	96.7	113.7	100.4
Kernel-stab	90.8 b	87.4 c	34.5	79.4 b	76.5 c	76.9	78.2 b	85.7 c	86.6	90.9 b	100.2 c	98.2	104.6	73.4	100.9	103.5	84.8
Silk channel control	118.8 a	94.1	bc 46.7	110.1 a	93.9 ab	75.6	94.2 a	93.0 ab	93.4	93.2 b	115.4 at	94.2	112.4	80.2	101.9	108.6	94.1
Kernel-stab control	119.0 a	105.6	ab 48.3	115.1 a	95.3 a	75.4	97.5 a	96.9 a	84.6	105.1 a	120.0 a	106.4	107.8	88.0	108.4	107.4	84.7
Natural	109.2 a	112.3 a	45.3	105.0 a	93.6 ab	76.0	89.1 a	95.9 a	95.5	94.7	at 114.7 at	100.4	111.6	76.8	95.4	105.7	115.6
Mean	109.3	98.5	43.7	102.4	88.9	75.5	89.8	91.6	87.6	96.1	110.7	101.9	109.1	77.8	100.6	107.7	96.1
P	0.001	0.002	0.086	0.001	0.001	0.964	0.001	0.004	0.071	0.042	0.007	0.163	0.962	0.664	0.664	0.855	0.139
C.V. %	0.16	0.21	0.26	0.19	0.13	0.19	0.15	0.12	0.23	0.16	0.14	0.23	0.29	0.33	0.28	0.26	0.42

C.V.% = coefficient of variability or (standard deviation / mean)*100
 Same letters across treatment for each environment were not different at the 0.05 level of probability.

3.4.3 Correlations between ear rot ratings and dry weight

To estimate the effect of ear rot damage on maize yields, correlations between ear rot ratings obtained across 17 environments and dry weight were computed for each inoculation method. Dry weight was significantly reduced ($r = -0.77$, $p < 0.01$, $n = 17$) with an increment in ear rot rating across genotypes inoculated with the kernel-stab inoculation technique (Fig. 3.2). The estimated reduction in dry weight is in the range of 41% to 60% with ear rot ratings ranging from 3.0 to 4.5. This association was not found for the silk channel inoculated genotypes, most likely because ear rot ratings achieved with this technique were below critical ratings of 3.0 to 3.5. The effect of ear rot damage on maize yield estimates has not been documented before. This association shows that kernel-stab inoculation technique is a better technique to achieve more severe levels of gibberella ear rot infection.

3.4.4 Ranking differences

Ranking the best genotypes from low to high performance according to visual ear rot and dry weight is a first attempt to select the genotypes with the best disease resistance across environments. However, the ranking of a particular genotype can change according to locations indicating poor stability across environments. The Lin and Binn's cultivar performance test allows the comparison of genotypes to the maximum yield observed in a particular location (Tables 3.7a and 3.7b). Their GxE statistics represent the square value of the differences between a genotype's variable mean and the maximum mean observed at a particular environment and divided by twice the number of environments.

This ranking analysis shows that maize hybrid G4106 and K127 are the best genotypes for low ear rot rating (highest GXE statistic) and the susceptible inbred line CO266 is the worst as expected across both silk channel and kernel-stab inoculations. Genotypes with the smallest GXE statistic value tend to have larger yields and are more stable (Lin and Binns 1986). The stability for ear rot resistance appears also to be better for inbred line CO325 across environments compared to other inbreds but not superior to

Figure 3.2. Linear regression between fusarium ear rot rating (FEER) and ear dry weight for nine genotypes with silk channel and kernel-stab inoculation methods and under natural infection.

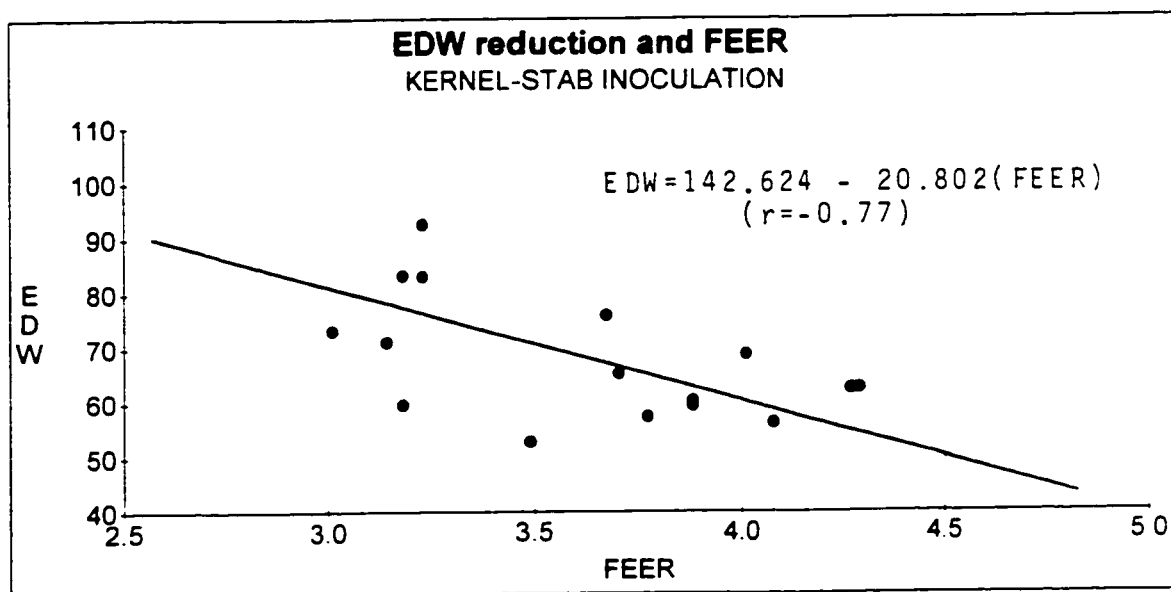
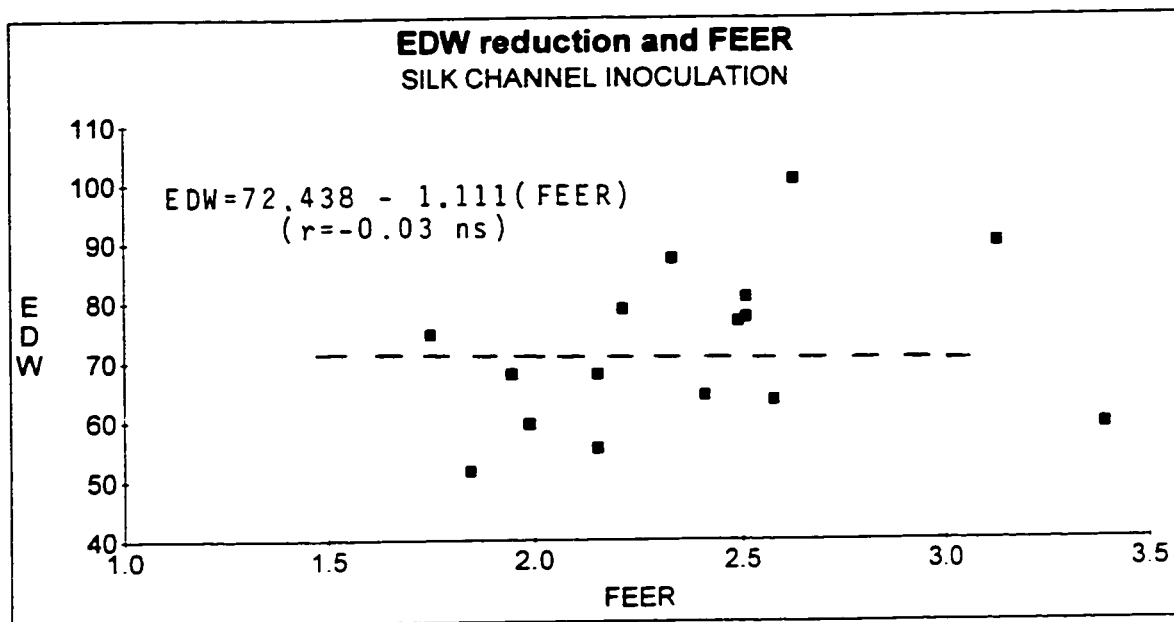


Table 3.7a. Genotype superiority measures across environments according to Lin and Binn's GXE statistics for ear rot.

Genotype	Performance GXE statistic* (ranking)
<i>silk channel inoculation method</i>	
G4106	3.84 (1)
CO325	3.25 (2)
CO272	3.12 (3)
K127	2.82 (4)
P3953	2.05 (5)
DK415	1.75 (6)
CO265	1.61 (7)
P3902	1.12 (8)
CO266	0.36 (9)
<i>kernel inoculation method</i>	
K127	2.73 (1)
G4106	2.70 (2)
CO325	2.38 (3)
P3902	2.00 (4)
P3953	1.12 (5)
CO265	1.04 (6)
DK415	0.84 (7)
CO272	0.66 (8)
CO266	0.43 (9)

() ranking from best ear rot resistance to worst.

* Lin and Binn (1988b)

Table 3.7b. Genotype superiority measure across environments according to Lin and Binn's GXE statistics for dry weight (g/ear).

Genotype	Performance GXE statistic* (ranking)
<i>silk channel inoculation method</i>	
P3902	115.54 (1)
G4106	134.45 (2)
P3953	196.69 (3)
DK415	314.94 (4)
K127	334.95 (5)
CO265	2732.88 (6)
CO325	2737.80 (7)
CO266	2890.51 (8)
CO272	3991.98 (9)
<i>kernel inoculation method</i>	
P3902	60.63 (1)
G4106	127.88 (2)
DK415	217.70 (3)
P3953	278.54 (4)
K127	309.91 (5)
CO325	2257.40 (6)
CO265	2588.15 (7)
CO266	2731.50 (8)
CO272	3443.16 (9)
() ranking from best to worst yield.	
* Lin and Binn (1988b)	

hybrid G4106 and for both inoculation methods. However, grain yield ranking is lower among inbred lines as expected, due to the heterosis effect in maize hybrids.

3.4.5 Joint regression model

The model, as explained earlier, is based on linear regression analysis across environments for each genotype under investigation. The “environmental index” that has been popularized by Finlay and Wilkinson (1963) represents the index as the mean value of a variable under investigation obtained across genotypes for a particular environment.

3.4.5.1 Heterogeneity between regression lines and genotype x environment interaction

Preliminary analysis of variance computed across all environments shows significant genotype x environment interactions for both inoculation methods and for natural background infection (Tables 3.8 and 3.9). Ear rot and dry weight data were analyzed with the joint regression model using the original genotype and environmental main effects computed in the ANOVA but partitioning the genotype x environment interaction based upon the heterogeneity between the regression lines obtained for each genotype (Eberhart and Russell 1966).

The heterogeneity between the genotype regression lines sum of squares accounted for 57% and 45% of the total genotype x environment interaction, respectively for visual ear rot and dry weight obtained with silk channel inoculation (Tables 3.10a, 3.10b, 3.11a, 3.11b). Heterogeneity for ear rot ratings was 10% lower with the kernel-stab inoculation, showing a smaller divergence in genotypic response with this method. The environmental heterogeneity accounted for 27% and 36% of the total genotype x environment interaction for visual rating obtained with silk channel and kernel-stab inoculations. Under low infection pressure, as expressed by the natural background infection, this heterogeneity accounted for only 10% of the visual rating expressed across genotypes. These findings are in accordance with earlier findings in resistance studies for fusarium head blight in winter wheat where heterogeneity values between lines were of

Table 3.8. Analysis of variance for ear rot ratings for all genotypes and environments.

Term	df	SS	MS	F-test	P
<i>silk channel inoculation</i>					
Model	152	637.396	4.193	12.80	0.0001
Genotype (G)	8	253.020	31.628	96.50	0.0001
Environment (E)	16	99.516	6.220	18.98	0.0001
G*E	128	259.586	2.028	6.19	0.0001
Error	417	136.664	0.328		
Total	569	774.060			
<i>kernel stabbing inoculation</i>					
Model	150	490.975	3.273	11.58	0.0001
Genotype	8	164.453	20.557	72.72	0.0001
Environment	16	104.398	6.525	23.08	0.0001
G*E	126	166.249	1.319	4.67	0.0001
Error	403	113.923	0.283		
Total	553	604.897			
<i>background natural infection</i>					
Model	152	147.509	0.971	18.67	0.0001
Genotype	8	85.632	10.704	205.91	0.0001
Environment	16	6.033	0.377	7.25	0.0001
G*E	128	53.511	0.418	8.04	0.0001
Error	422	21.938	0.052		
Total	574	169.447			

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

Table 3.9. Analysis of variance for dry weight for all genotypes and environments.

Term	df	SS	MS	F-test	P
<i>silk channel inoculation</i>					
Model	146	663793.661	4546.532	8.71	0.0001
Genotype (G)	8	365221.628	45652.704	87.47	0.0001
Environment (E)	16	69454.488	4340.906	8.32	0.0001
G*E	122	133248.616	1092.202	2.09	0.0001
Error	377	196772.114	521.942		
Total	523	860565.775			
<i>kernel-stab inoculation</i>					
Model	146	558707.666	3826.765	10.64	0.0001
Genotype	8	325337.949	40667.244	113.04	0.0001
Environment	16	52477.933	3279.871	9.12	0.0001
G*E	122	75705.891	620.540	1.72	0.0001
Error	373	134195.390	359.773		
Total	519	692903.056			
<i>background natural infection</i>					
Model	148	635800.284	4295.948	9.55	0.0001
Genotype	8	382879.375	47859.922	106.44	0.0001
Environment	16	76813.004	4800.813	10.68	0.0001
G*E	124	86133.597	694.626	1.54	0.0001
Error	378	169965.082	449.643		
Total	526	805765.367			

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

Table 3.10a. Summary of the results for the Joint regression analysis for fusarium ear rot rating (FEER) over silk channel inoculation.

Term	df	SS	MS	F-test	P
Genotype (G)	8	253.338	31.667	108.450	0.0001
Environment (E) + G*E	144	355.017 (100%)			
E (linear)	1	94.663 (27%)	94.663		
G*E (linear)	7	203.671 (57%)	29.096	69.775	0.01
Pooled deviation	136	56.683 (16%)	0.417	1.546	NS
Pooled error	366	106.873	0.292		

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

Table 3.10b. Summary of the results for the Joint regression analysis for ear rot rating over kernel-stab inoculation.

Term	df	SS	MS	F-test	P
Genotype (G)	8	159.967	19.996	72.930	0.0001
Environment (E) + G*E	142	258.328 (100%)			
E (linear)	1	94.409 (36%)	94.409		
G*E (linear)	7	120.773 (47%)	17.253	53.581	0.01
Pooled deviation	134	43.146 (17%)	0.322	1.175	NS
Pooled error	352	96.516	0.274		

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

Table 3.11a. Summary of the results for the Joint regression analysis for mean dry weight with silk channel inoculation.

Term	df	SS	MS	F-test	P
Genotype (G)	8	363111.571	45388.946	88.000	0.0001
Environment (E) + G*E	138	198601.42 (100%)			
E (linear)	1	66857.423 (34%)	66857.423		
G*E (linear)	7	89822.509 (45%)	12831.787	39.792	0.01
Pooled deviation	130	41921.496 (21%)	322.473	0.625	NS
Pooled error	326	168154.333	515.811		

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

Table 3.11b. Summary of the results for the Joint regression analysis for mean dry weight with kernel-stab inoculation.

Term	df	SS	MS	F-test	P
Genotype (G)	8	312605.636	39075.705	109.030	0.0001
Environment (E) + G*E	138	124956.150 (100%)			
E (linear)	1	49905.866 (40%)	49905.866		
G*E (linear)	7	53422.878 (43%)	7631.840	45.870	0.01
Pooled deviation	130	21627.406 (17%)	166.365	0.460	NS
Pooled error	322	115401.456	358.390		

df= degree of freedom; SS= sum of squares; MS= mean squares; NS= non significant.

similar magnitude (Snijders and Van Eeuwijk 1991).

The unexplained deviations (pooled deviations) from the regression lines on the environmental index were relatively low at about 17%. These deviations were similar for ear rot rating and ear dry weight and for both inoculation treatments. Therefore, the joint regression model gave very good results in explaining the deviations.

3.4.5.2 Stability of the joint regression model

The stability analysis expressed by the ranking of the slopes and the deviation variances obtained with the genotype regression lines fitted over the environment index shows a good stability for ear rot resistance of maize hybrid G4106 (slope= 0.122, deviation variance= 0.107) under silk inoculation (Table 3.12). This genotype is followed closely by inbred line CO325 (slope= 0.231) with a low ear rot rating across environments and line CO272 (slope= 0.530). However a low value for the regression line coefficient of determinations observed for CO325 showing a low reliability for this line with the silk channel inoculation. Under kernel-stab inoculation, G4106 maintains a stable disease resistance but its regression line has a poor fit compared to Pioneer 3902, K127 and CO265 which appear to be more stable. Line CO325 ranks sixth on the overall ranking out of nine genotypes. The joint regression model gives hybrid G4106 as the most stable genotype for resistance, as reported in the Lin-Binns GXE statistic.

On the grain yield side, the Lin and Binns GXE statistics gives a stable record for G4106 across environments with the highest dry weight with both inoculation methods (Table 3.13). Hybrid K127, characterized by a smaller ear size, is a poor performer in terms of yields contrary to its disease resistance. In fact, it was surpassed by all the other hybrid lines in the test, making G4106, the best overall performer for both yields and ear rot resistance. Among inbred lines, the best performer for yield is CO325 under kernel-stab inoculation. Interestingly, line CO266, the most susceptible genotype gave a stable yields under silk but not under kernel inoculation.

Table 3.12. Stability analysis and ranking according to genotype regression lines computed by the joint regression model for ear rot rating.

Genotype	Slope b (ranking)	Intercept	Deviation variance (ranking)	Coefficient of determination (R ²)	Ear rot rating N ¹	Overall ¹ ranking (ranking)
<i>silk channel inoculation</i>						
G4106	0.12 (1)	1.28	0.107 (1)	0.031 ns 17	1.58 (1)	1
CO325	0.23 (2)	1.20	0.536 (7)	0.022 ns 16	1.76 (2)	2
CO272	0.53 (3)	0.61	0.357 (3)	0.153 ns 15	1.89 (3)	3
K127	0.85 (5)	-0.10	0.208 (2)	0.443 ** 15	1.95 (4)	4
P3953	1.42 (7)	-1.10	0.378 (4)	0.549 ** 17	2.33 (5)	5
CO266	1.50 (8)	0.16	0.450 (6)	0.534 ** 15	3.78 (9)	6
CO265	1.37 (6)	-0.71	0.376 (4)	0.533 ** 16	2.60 (6)	6
DK415	0.65 (4)	1.11	0.717 (9)	0.120 ns 17	2.68 (7)	8
P3902	2.20 (9)	-2.13	0.649 (8)	0.631 ** 17	3.18 (8)	9
<i>kernel-stab inoculation</i>						
G4106	0.07 (1)	2.76	0.107 (2)	0.014 ns 16	3.01 (1)	1
P3902	0.47 (2)	1.57	0.097 (1)	0.449 ** 15	3.33 (4)	2
K127	0.78 (4)	0.08	0.177 (3)	0.550 ** 17	2.99 (1)	3
CO265	1.20 (7)	-0.52	0.200 (5)	0.718 ** 14	3.89 (5)	4
P3953	0.79 (5)	0.93	0.154 (4)	0.589 ** 15	3.87 (5)	4
DK415	0.53 (3)	2.16	0.217 (6)	0.317 * 14	4.15 (7)	6
CO325	0.87 (6)	-0.04	0.376 (7)	0.413 ** 15	3.18 (3)	6
CO266	1.36 (8)	-0.51	0.470 (8)	0.583 ** 16	4.57 (9)	8
CO272	1.61 (9)	-1.54	1.169 (9)	0.440 ** 13	4.38 (8)	9

Table 3.13. Stability analysis and ranking according to genotype regression lines computed by the joint regression model for grain dry weight per ear.

Genotype	Slope b (ranking)	Intercept	Deviation variance (ranking)	Coefficient of determination (R ²)	Ear rot rating N ¹	Overall ¹ ranking (ranking)
<i>silk channel inoculation</i>						
G4106	1.09 (1)	19.94	153.434 (4)	0.705 ** 15	97.40 (1)	1
P3953	0.88 (2)	29.60	235.616 (7)	0.501 ** 17	91.92 (3)	2
P3902	1.23 (3)	10.03	245.983 (8)	0.652 ** 17	96.97 (2)	2
DK415	0.60 (5)	45.98	157.722 (5)	0.320 * 16	89.97 (4)	4
K127	0.51 (6)	51.01	206.571 (6)	0.281 * 15	87.43 (5)	5
CO266	1.34 (4)	-45.62	1539.764 (9)	0.261 ns 10	48.95 (6)	5
CO325	0.43 (7)	8.24	123.895 (3)	0.317 * 16	38.95 (7)	7
CO265	0.31 (8)	13.77	95.443 (2)	0.191 ns 15	35.02 (8)	8
CO272	0.10 (9)	9.28	72.568 (1)	0.033 ns 11	16.06 (9)	9
<i>kernel-stab inoculation</i>						
G4106	1.03 (2)	22.86	185.716 (6)	0.584 ** 15	90.97 (2)	1
DK415	1.00 (1)	18.35	159.883 (4)	0.472 ** 14	86.43 (3)	2
P3953	1.13 (3)	5.41	86.874 (1)	0.795 ** 15	79.21 (5)	2
P3902	1.16 (4)	18.16	109.299 (3)	0.765 ** 16	93.92 (1)	2
K127	0.52 (6)	46.37	186.162 (7)	0.281 * 17	80.65 (4)	5
CO325	0.26 (7)	19.90	165.211 (5)	0.099 ns 15	37.00 (6)	5
CO266	0.56 (5)	-8.28	205.834 (8)	0.290 ns 12	28.54 (8)	7
CO265	0.28 (8)	16.03	304.614 (9)	0.059 ns 14	33.89 (7)	7
CO272	0.45 (9)	-9.70	87.379 (2)	0.352 ns 7	18.55 (9)	9

() Ranking across genotypes; ¹ overall approx. ranking= median ranking of slope b=1, deviation variance= 0 and ear rot rating; ¹ N= number of observations; * significance at the 0.05 level, ** at the 0.01 level, ns= non significant coefficient of determination.

The graphical expression of the regression lines for each genotype across the environmental index reveals a good stability for resistance with inbred line CO325 under silk channel inoculation (Fig. 3.4a). However, this trend was less obvious under kernel inoculation (Fig. 3.4b). Adaptability for the hybrid lines sub-group, shows that G4106 resistance is consistent across silk and kernel inoculations with a near horizontal regression line across environments (Figs. 3.4c and 3.4d). The stability for ear rot resistance observed for hybrid K127 is less obvious through its graphical representation since its slope value is closer to one (slope= 0.849). On the other hand, yield adaptability as expressed by dry weight was in favor of inbred line CO325 for kernel-stab inoculated plants (Fig. 3.3a and 3.3b). For the maize hybrid sub-group, stability was obvious except for genotype K127 which show the lowest ranking for stability (Figs. 3.3c and 3.3d).

As a general assessment for the joint regression model, we can say that if the model had been able to capture all the genotype by environment interactions, all the genotype regression lines across the environmental index should have intersected at a single point (Gauch 1992). This concurrence of the regression lines is not expressed clearly in the present data, therefore the joint regression model is not the perfect approach to explain all the genotype x environment interactions. However, the model accounts for 83% of the interaction observed in ear rot ratings and dry weight, which is quite good leaving only 17% of the unexplained interaction in the residuals for this large data set. In an attempt to capture more of the genotype x environment interaction the **AMMI** model was applied with its multiplicative approach using a variation of the principal component analysis.

Figs. 3.3a-3.3d. Genotype stability analyses across 17 environments for grain dry weight (g/ear) according to the joint regression model described by Eberhart and Russell:

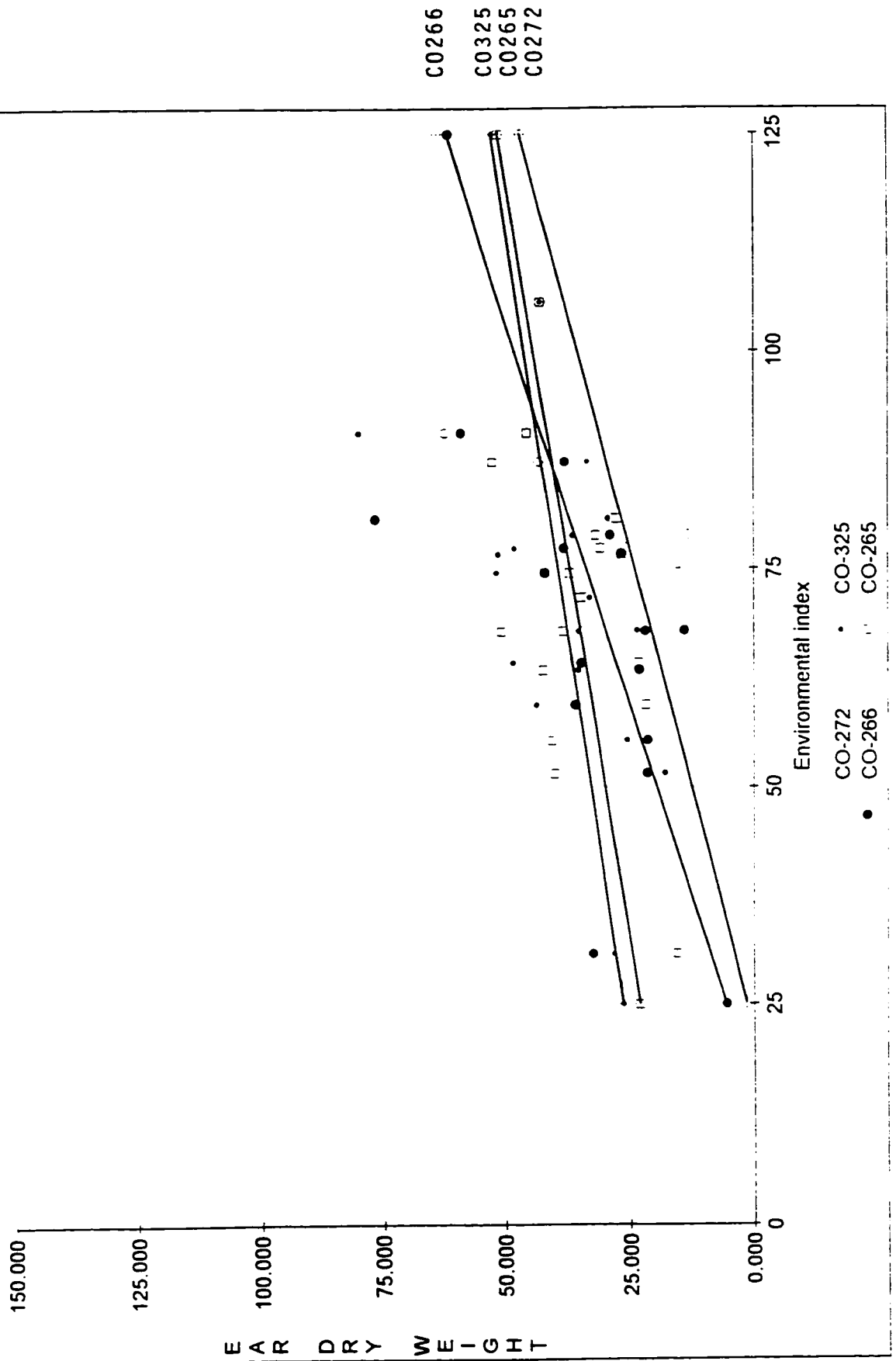
Fig. 3.3a. Inbred sub-group with silk channel inoculation.

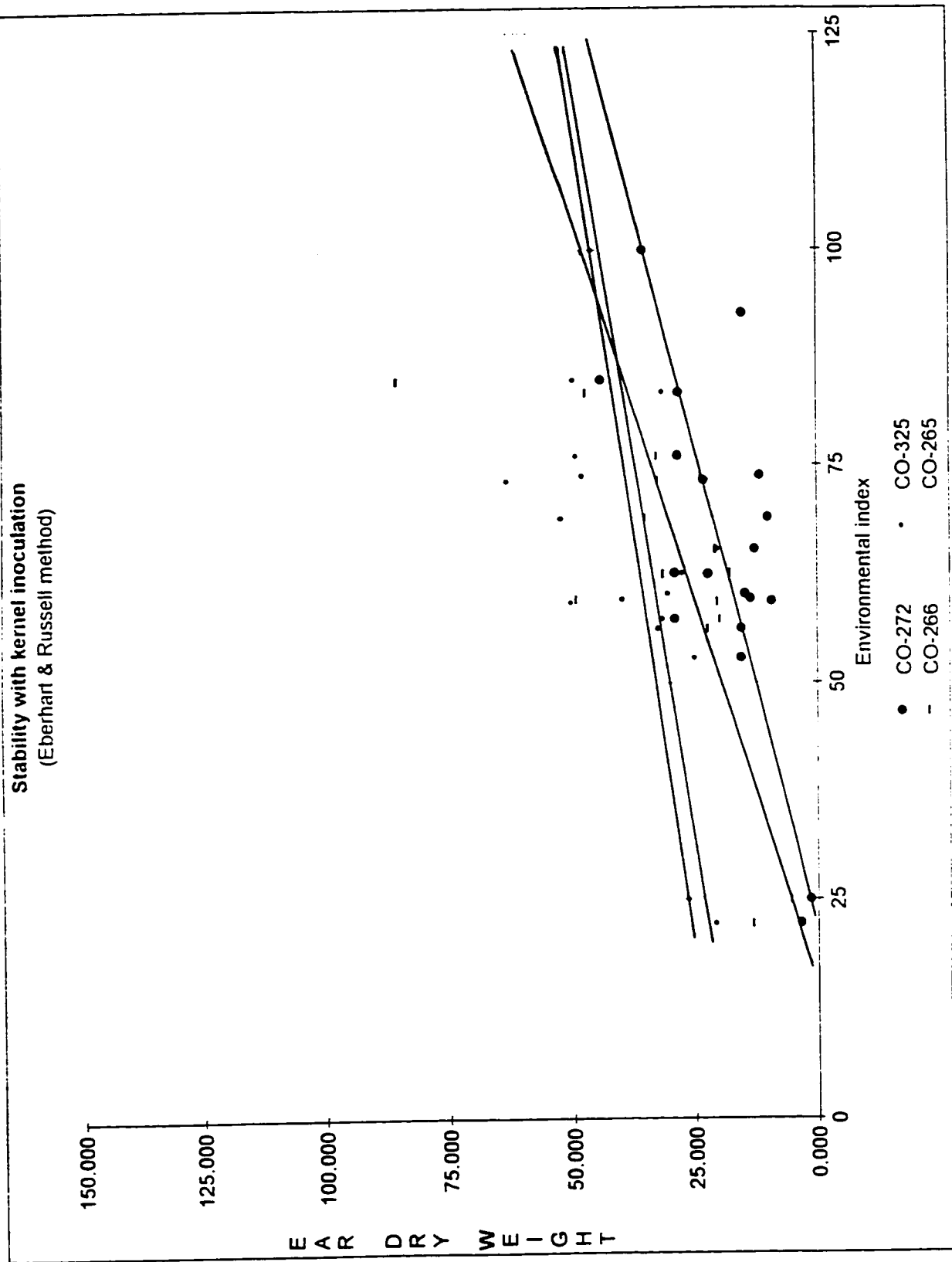
Fig. 3.3b. Inbred sub-group with kernel-stab inoculation.

Fig. 3.3c. Hybrid sub-group with silk channel inoculation.

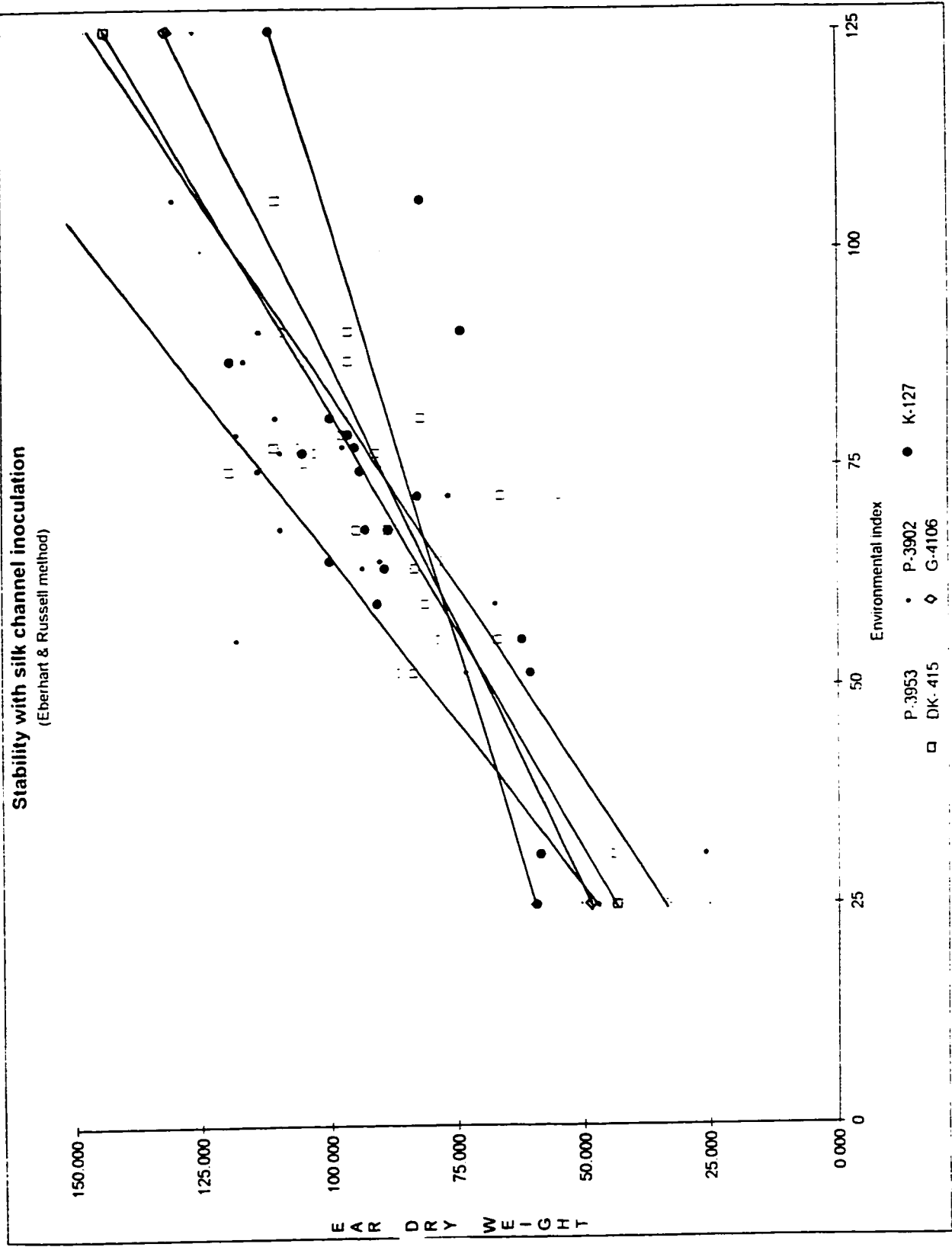
Fig. 3.3d. Hybrid sub-group with kernel-stab inoculation.

Stability with silk channel inoculation
(Eberhart & Russell method)

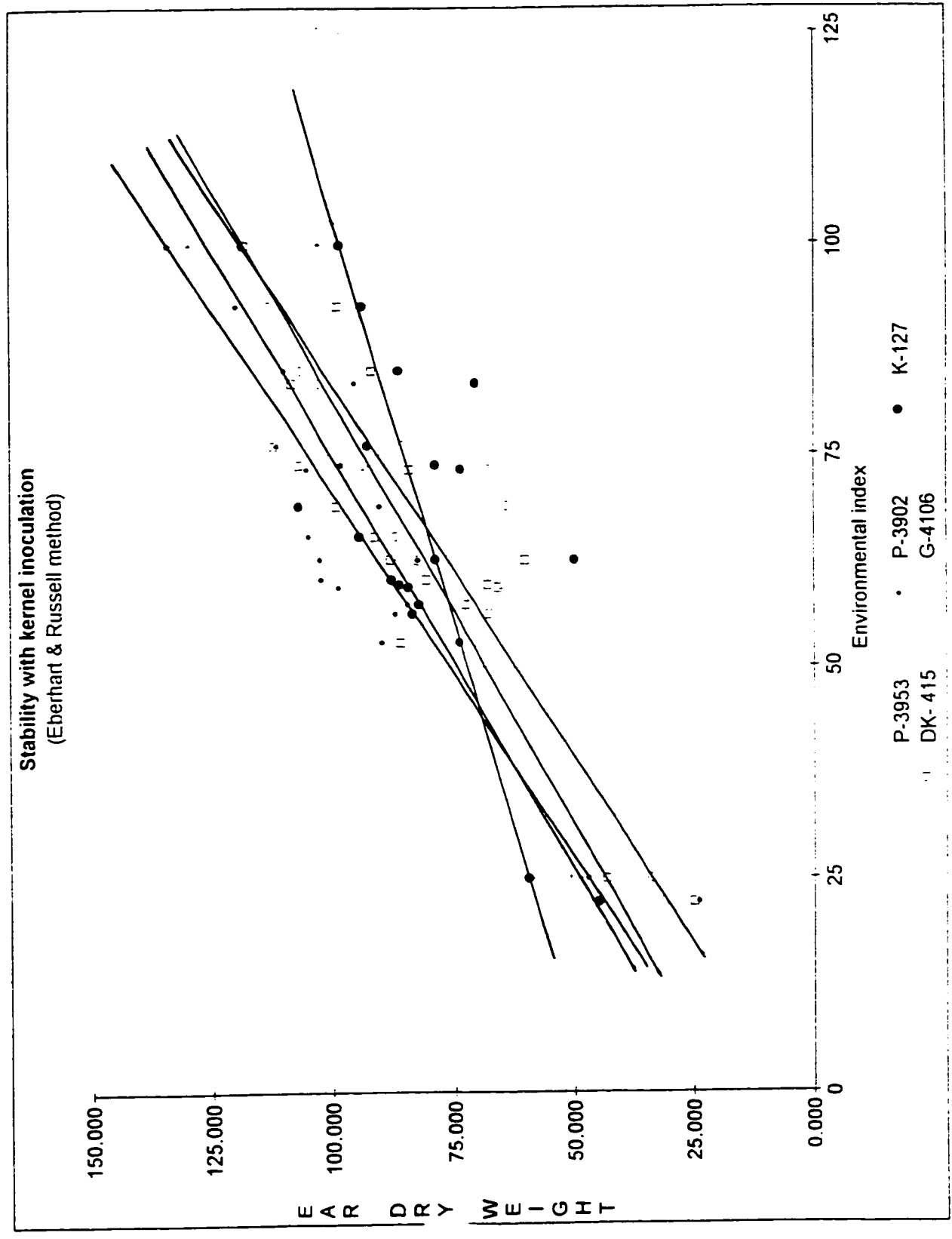




C0266
C0325
C0265
C0272



P3902
P3953
DK415
G4106
K127



P3902
G4106
P3953
DK415
K127

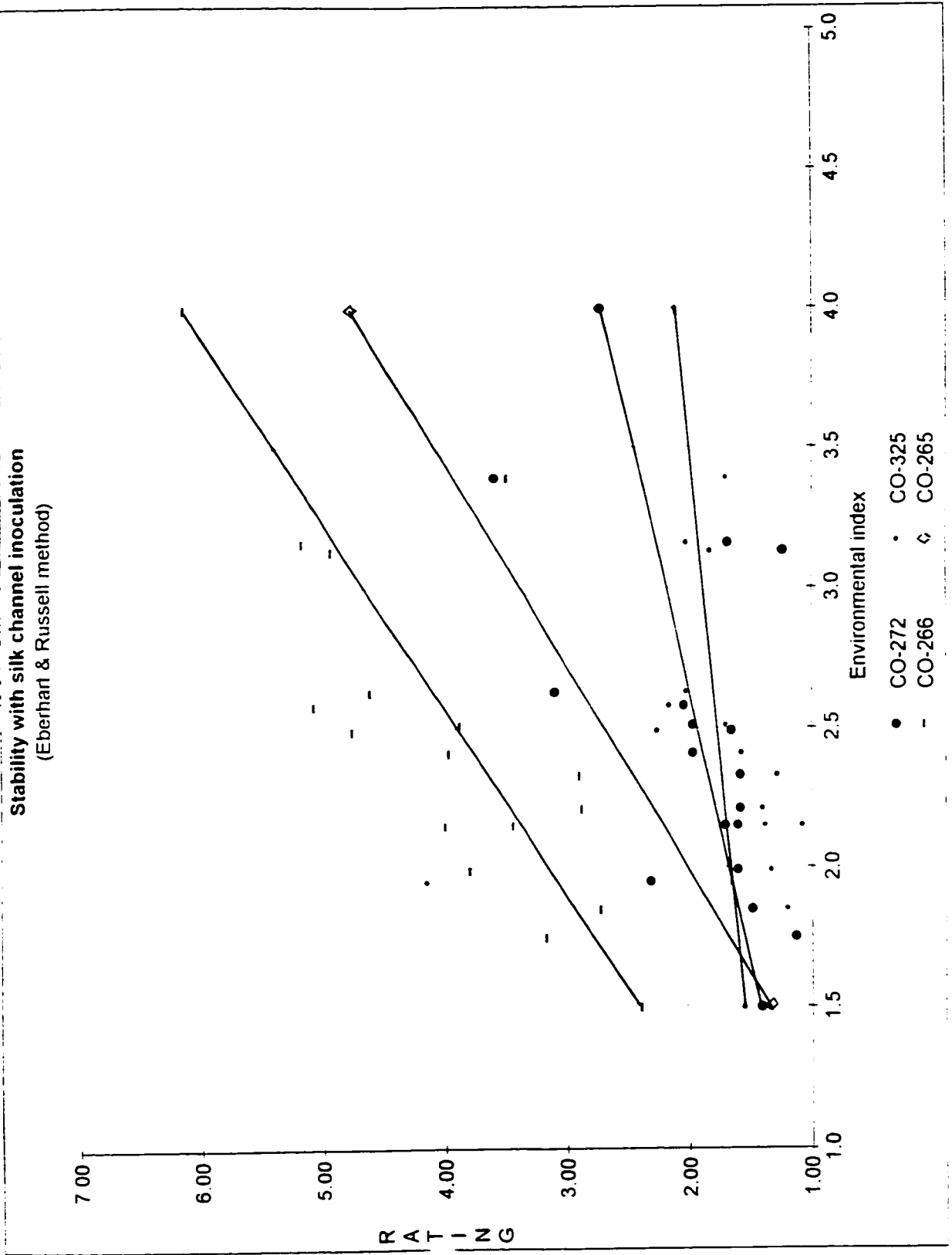
Figs. 3.4a-3.4d. Genotype stability analyses across 17 environments for ear rot rating according to the joint regression model described by Eberhart and Russell:

Fig. 3.4a. Inbred sub-group with silk channel inoculation.

Fig. 3.4b. Inbred sub-group with kernel-stab inoculation.

Fig. 3.4c. Hybrid sub-group with silk channel inoculation.

Fig. 3.4d. Hybrid sub-group with kernel-stab inoculation.

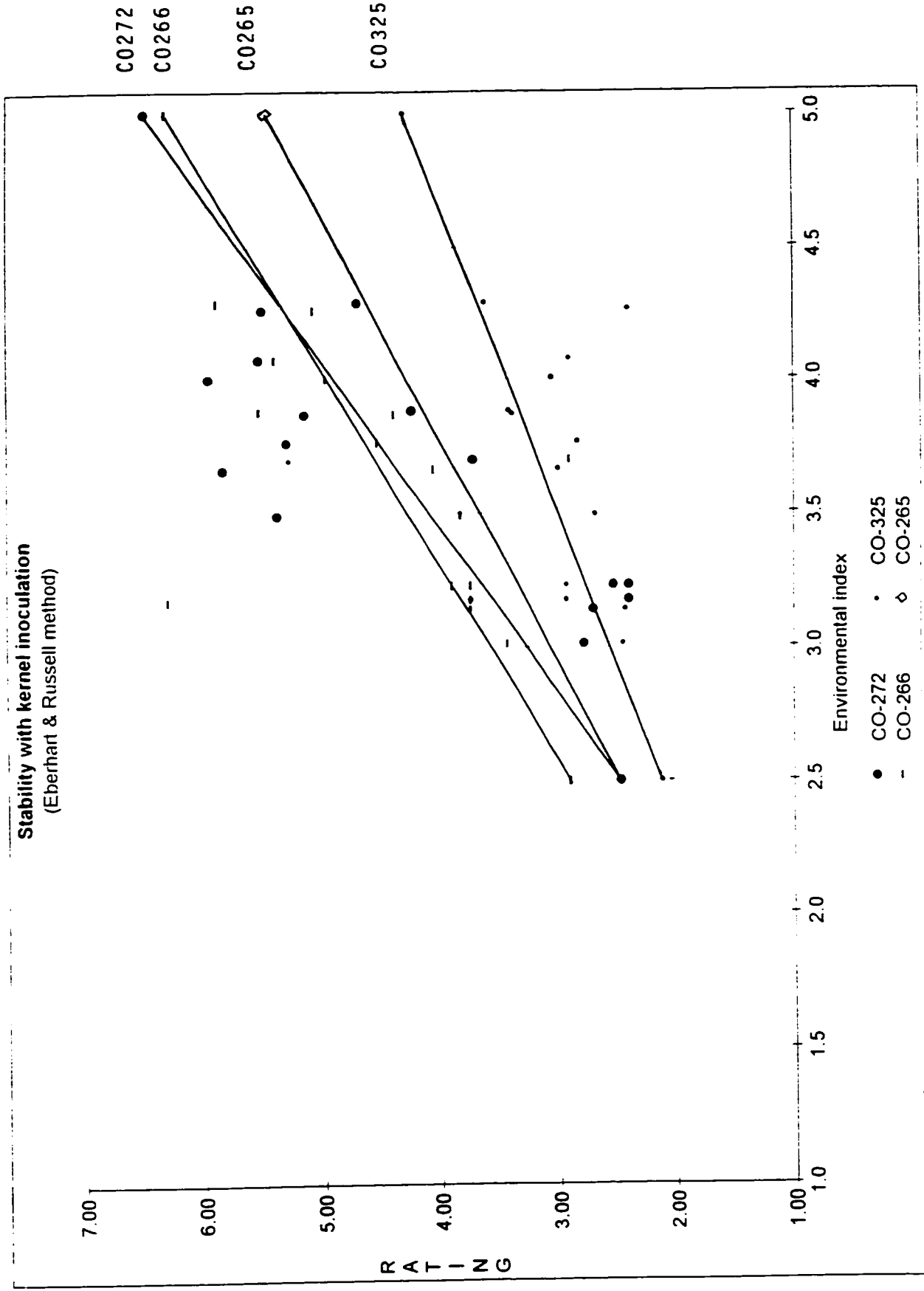


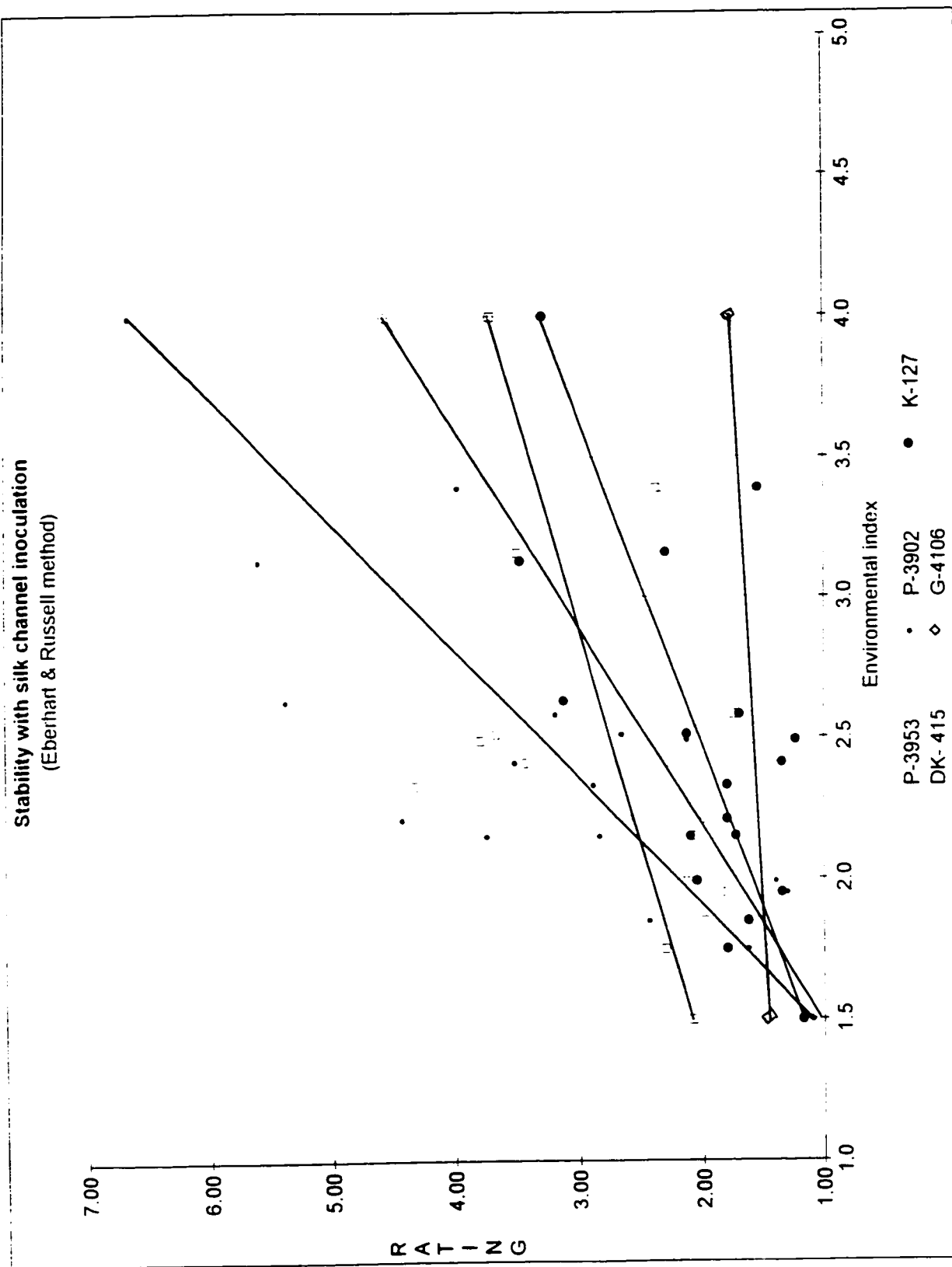
C0266

C0265

C0272

C0325





P3902

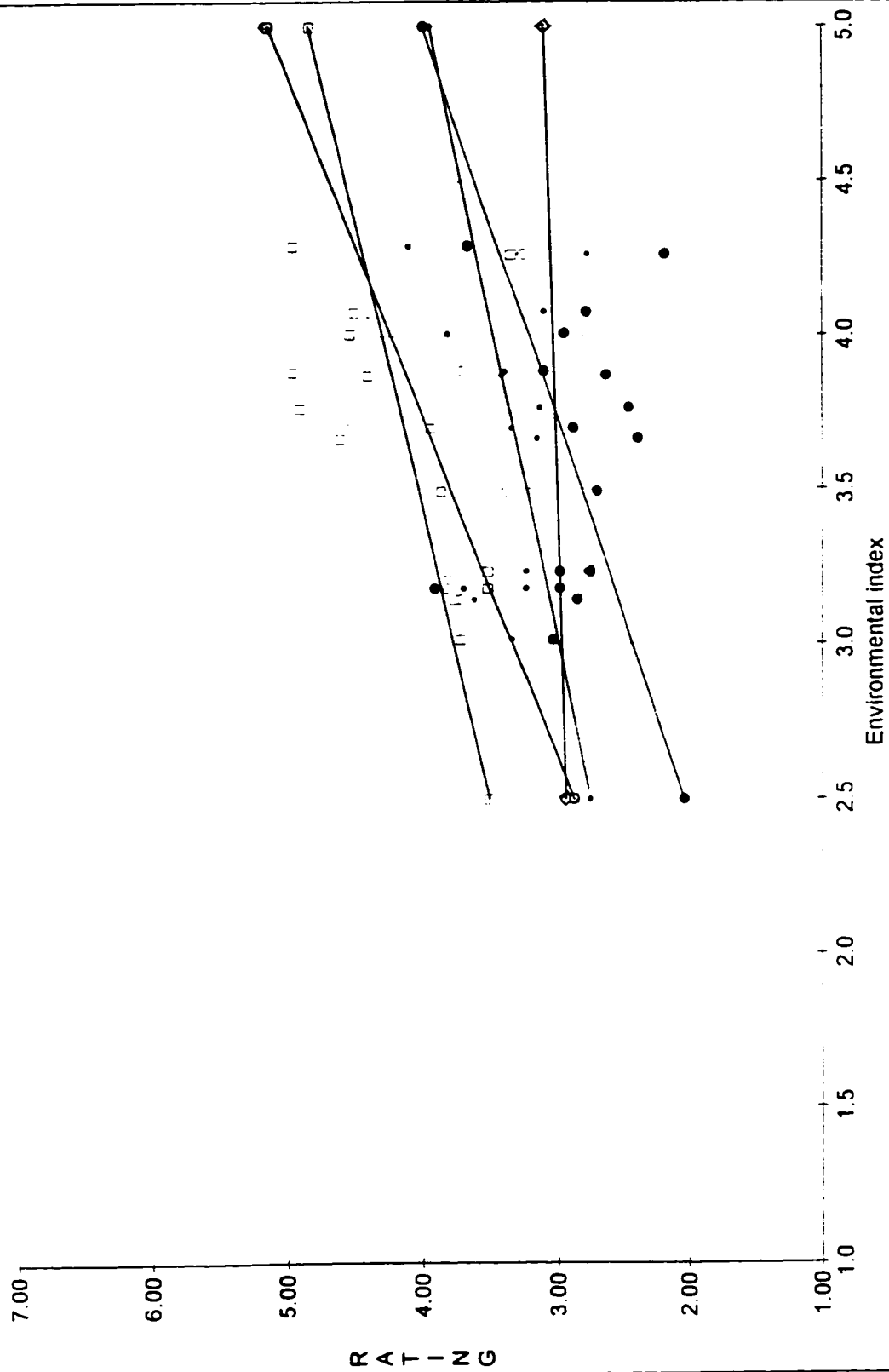
P3953

DK415

K127

G4106

Stability with kernel inoculation
(Eberhart & Russell method)



P3953
DK415
K127
P3902
G4106

3.4.6 AMMI model and genotype x environment interactions

Due to some software program limitations with the AgroBase™ statistical package, some data transformations were necessary to achieve the AMMI analysis. The data were analyzed using a mean file with all the basic statistical parameters extracted from the ANOVA analysis as recommended by the AMMI method (Zobel *et al.* 1988; Zobel and Wallace 1995; Baker 1996). The mean file consisted of adjusted means because no provision for missing values is made by the program. The AgroBase™ AMMI program constructed a partial ANOVA table and its multiplicative interpretation of genotype x environment interaction through AMMI modified principal component analysis (IPCA) scores which are similar to principal component analysis (PCA) scores, as explained in the above cited references.

3.4.6.1 Genotype by environment interaction and the AMMI Model

The genotype x environment interaction captured by the AMMI model shows that the first two IPCA scores can explain 60% and 75% of the interaction for ear rot ratings obtained with the silk channel and kernel-stab inoculations, respectively (Tables 3.14a and 3.14b). The IPCA scores calculated for dry weight captured 62% and 64% of the interaction for each inoculation method (Tables 3.15a and 3.15b). Therefore, the AMMI model appears to give a better fit to ear rot ratings with the kernel-stab inoculation.

So far, we can see that the capture of the interaction with the AMMI model with two IPCA scores is lower than that for the joint regression model which captured almost 20% more of the interaction. However, the model parameters shown graphically as a biplot with the variable means in abscissa (X-axis) and the first IPCA score in ordinate (Y-axis), reveal supplemental information concerning GE interactions. The biplot diagrams represent genotypes and environments closer to the origin (center) are entities with lower GE interactions.

Table 3.14a. Summary of results for the AMMI analysis for ear rot rating with silk channel inoculation.

Term	df	SS	MS	Approx. F-test	P
Genotype (G)	8	275.161	34.395	72.68	0.001
Reps within G	27	12.777	0.473		
Environment (E)	16	118.560	7.410	3.34	0.001
GE interaction	128	284.399 (100%)	2.222	7.08	0.001
IPCA 1	23	114.084 (40%)	4.960	15.80	0.001
IPCA 2	21	55.345 (20%)	2.635	8.39	0.001
IPCA Residual	84	114.970 (40%)			
Error	432	135.648	0.314		

df= degree of freedom; SS= sum of squares; MS= mean squares

Table 3.14b. Summary of results for the AMMI analysis for ear rot rating over kernel-stab inoculation.

Term	df	SS	MS	Approx. F-test	P
Genotype (G)	8	192.141	24.018	49.68	0.001
Reps within G	27	13.053	0.483		
Environment (E)	16	132.294	8.268	4.91	0.001
GE interaction	128	215.383 (100%)	1.683	6.08	0.001
IPCA 1	23	111.695 (52%)	4.856	17.54	0.001
IPCA 2	21	49.770 (23%)	2.635	8.56	0.001
IPCA Residual	84	53.918 (25%)			
Error	432	119.616	0.277		

df= degree of freedom; SS= sum of squares; MS= mean squares

Table 3.15a. Summary of the results from the AMMI analysis for mean dry weight with silk channel inoculation.

Term	df	SS	MS	Approx. F-test	P
Genotype (G)	8	559417.260	69927.157	168.40	0.001
Reps within G	27	11211.468	415.240		
Environment (E)	16	85930.824	5370.677	7.11	0.001
GE interaction	128	96685.961 (100%)	755.359	3.49	0.001
IPCA 1	23	37608.871 (39%)	1635.168	7.56	0.001
IPCA 2	21	22365.553 (23%)	1065.026	4.92	0.001
IPCA Residual	84	36711.537 (38%)			
Error	432	93489.600	216.411		

df= degree of freedom; SS= sum of squares; MS= mean squares

Table 3.15b. Summary of the results from the AMMI analysis for mean dry weight with kernel-stab inoculation.

Term	df	SS	MS	Approx. F-test	P
Genotype (G)	8	484948.822	60618.603	99.95	0.001
Reps within G	27	16374.990	606.481		
Environment (E)	16	81131.009	5070.688	6.40	0.001
GE interaction	128	101379.048 (100%)	792.024	2.76	0.001
IPCA 1	23	35670.002 (35%)	1550.870	5.40	0.001
IPCA 2	21	29149.431 (29%)	1388.068	4.83	0.001
IPCA Residual	84	36559.615 (36%)			
Error	432	124116.960	287.308		

df= degree of freedom; SS= sum of squares; MS= mean squares

A genotype with a low IPCA score, such as CO272 (A) or K127 (G) in the left quadrant has a superior ear rot resistance or low ear rot rating under silk channel inoculation (Fig. 3.5a). However, with kernel-stab inoculation, the genotypic resistance to disease is less obvious as it appears only for genotypes G4106 (I) and K127 (G) in the bottom left quadrant (Fig. 3.5b). Biplots show also that a greater GE interaction, as explained by the IPCA score for less stable conditions with silk inoculation ($IPCA1=1.51$ to 1.18) compared to kernel inoculation ($IPCA1=-0.72$ to 1.84). The least stable environments occur for COBDEN in 1996 (n) and St-POLYCARPE (k and q) in 1995 and 1996, respectively, and WINCHESTER in 1995 (j). Therefore, as observed for the joint regression model, the stability of genotype CO272 is noticed for ear rot resistance with the AMMI biplot but not for the CO325 line.

In the case of yield performance, we should consider a sub-grouping between inbred lines (A,B,C,D) and hybrids (E,F,G,H,I) due to the heterosis (Figs. 3.6a and 3.6b). Kernel-stab inoculation show to lower inbred lines yields to a greater extent than the silk method. Hybrid G4106 (I) and K127 (G) appear to be more stable across environments under both inoculation methods. Unstable environments for yields were encountered in Cobden 1994 for both inoculation techniques and in Ottawa 1996 (I) for silk channel and Nepean (m) for kernel-stab inoculation. Yield stability appeared also better among the hybrid sub-group with G4106 (I) and K127 (G) in the lead, showing the superiority of these two genotypes for both yield and ear rot resistance in the kernels.

As observed in earlier studies with the AMMI biplot, this additional information is helpful in establishing patterns that can also be subjected to agricultural and weather considerations to explain the genotype x environment interactions (Snijders and Eeuwijk 1991).

3.4.7 Weather effect on ear rot and dry weight

Positive correlations were found between ear rot ratings obtained with kernel-stab inoculation and number of days with high relative humidity in August (HUM2), and also

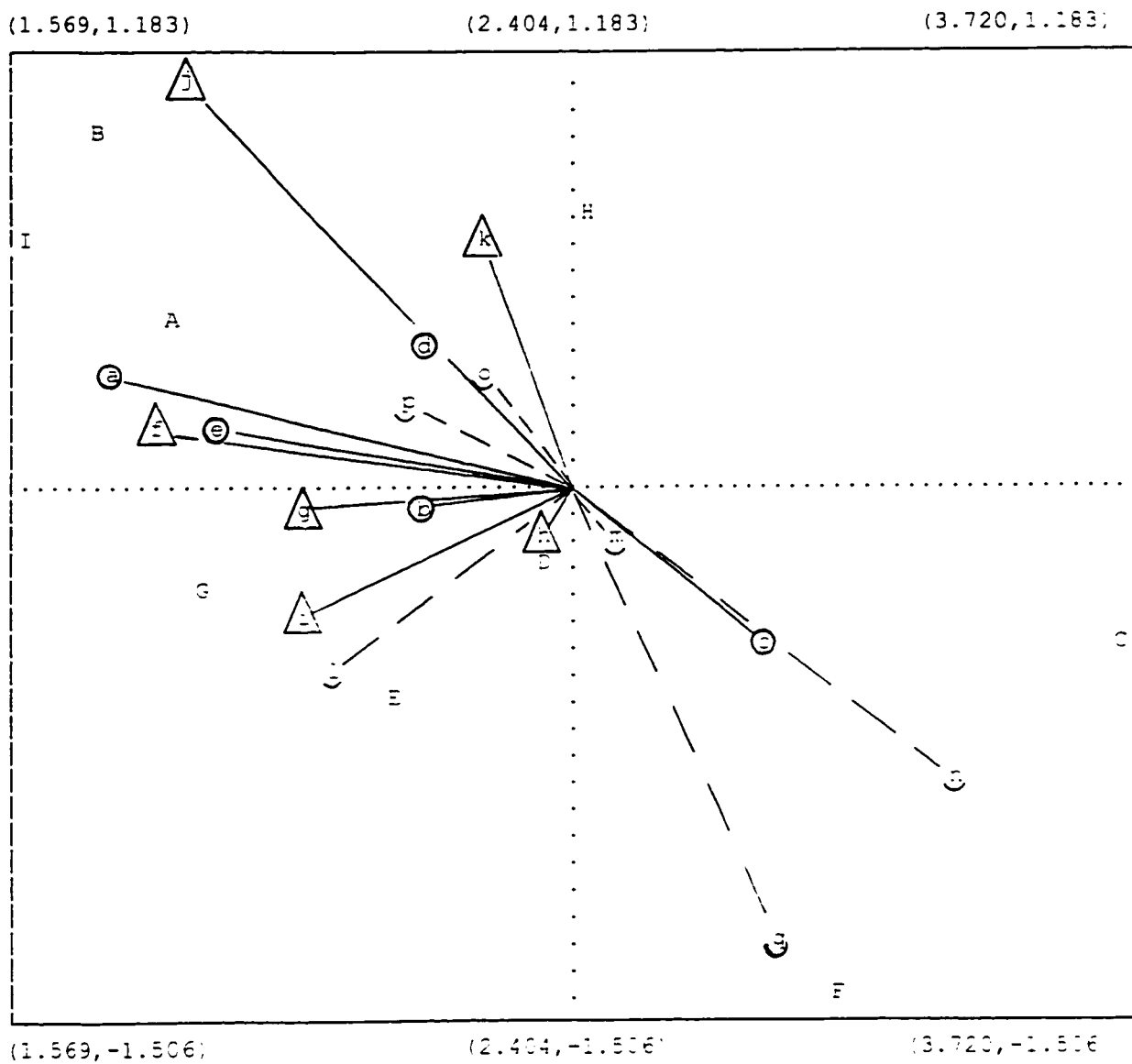
Figs. 3.5a - 3.6b. Biplot for fusarium ear rot on X-axis and IPCA1 score on Y-axis obtained from the AMMI model: environments are plotted as a, b, c, ..., and genotypes as A, B, C, ..., . Points located near the center are stable.

LEGEND

<u>Code</u>	<u>Location</u>	<u>Year</u>	<u>ENV-</u>
Ⓐ	OTTAWA (CEF)	1994	1
Ⓑ	NEPEAN (ARC)	1994	2
Ⓒ	COBDEN	1994	3
Ⓓ	PRESCOTT	1994	4
Ⓔ	WINCHESTER	1994	5
Ⓕ	OTTAWA	1995	6
Ⓖ	NEPEAN	1995	7
Ⓗ	COBDEN	1995	8
Ⓘ	PRESCOTT	1995	9
Ⓙ	WINCHESTER	1995	10
Ⓚ	ST-POLYCARPE	1995	11
Ⓛ	OTTAWA	1996	12
Ⓜ	NEPEAN	1996	13
Ⓝ	COBDEN	1996	14
Ⓞ	PRESCOTT	1996	15
Ⓟ	WINCHESTER	1996	16
Ⓠ	ST-POLYCARPE	1996	17

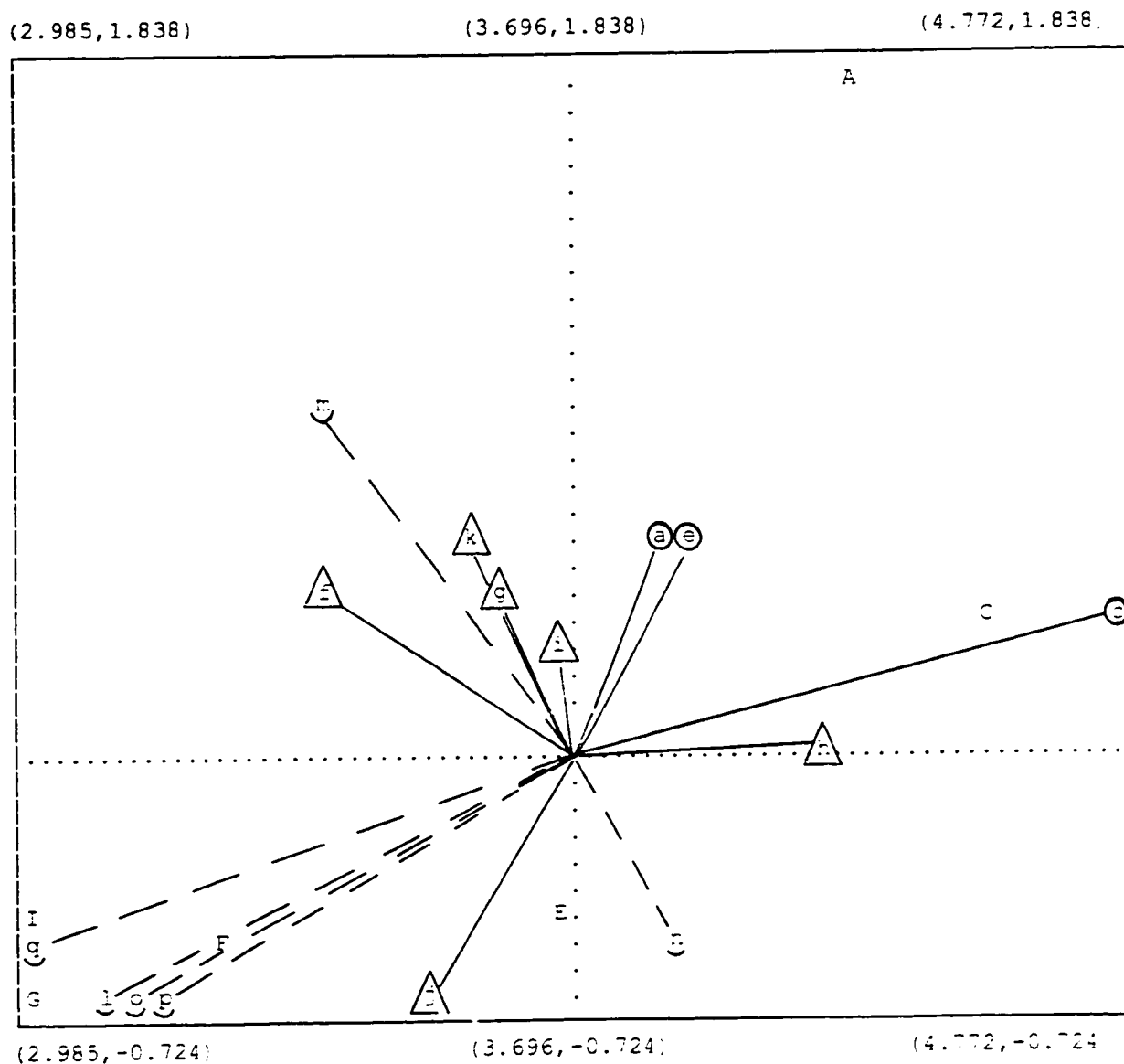
<u>Code</u>	<u>Inbred sub-group</u>	<u>Known resistance to fusarium ear rot</u>
A	CO272	moderate
B	CO325	high
C	CO266	very low
D	CO265	low
	<u>Hybrid sub-group</u>	<u>Known resistance to fusarium ear rot</u>
E	P3953	low
F	P3902	low
G	K127	moderate
H	DK415	low
I	G4106	moderate

Fig. 3.5a. Biplot for fusarium ear rot obtained with silk channel inoculation on X-axis and IPCA1 score on Y-axis obtained from the AMMI model: environments are plotted as a, b, c, ..., and genotypes as A, B, C, ..., . Points located near the center are stable.



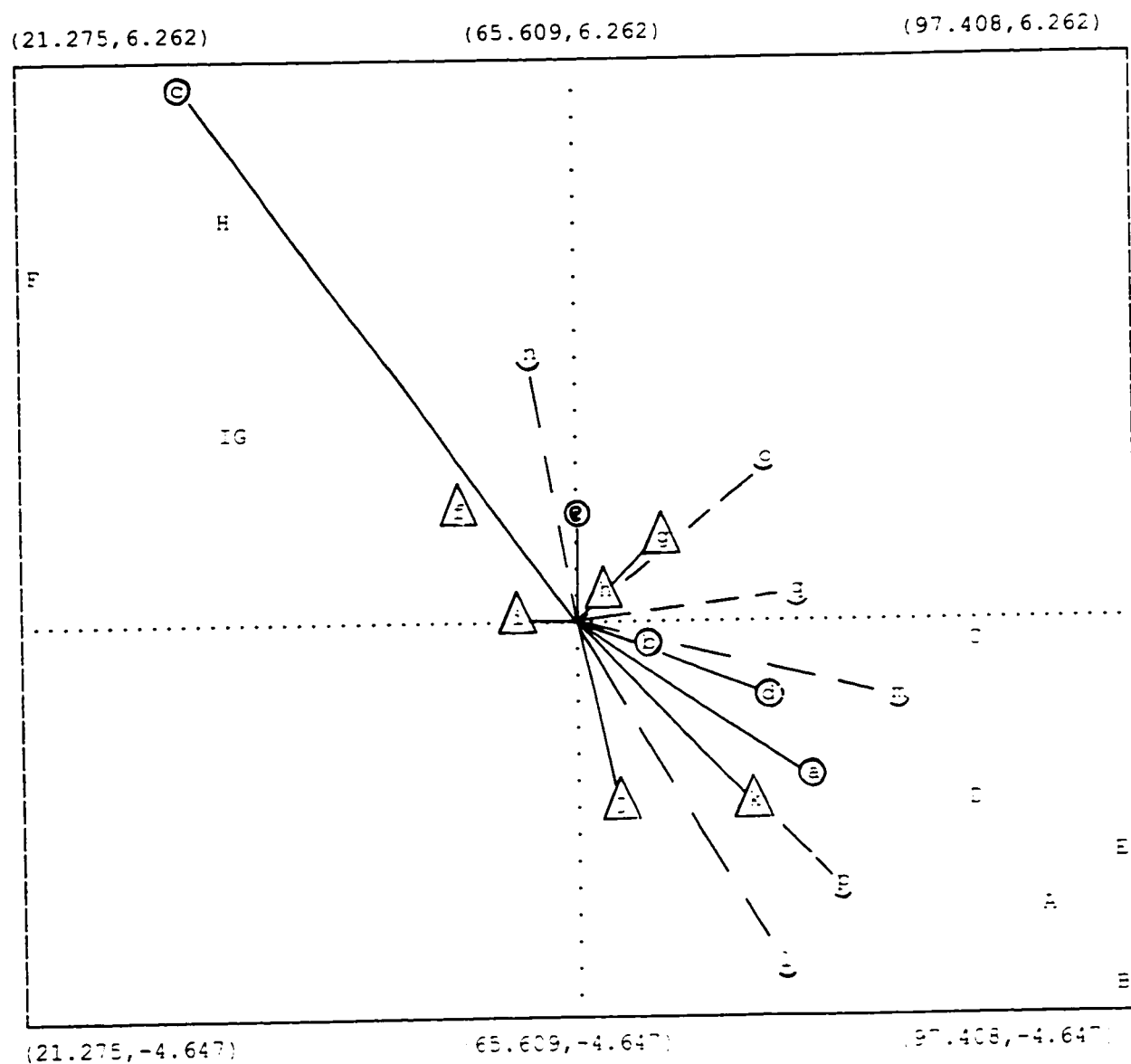
AGROBASE

Fig. 3.5b. Biplot for fusarium ear rot obtained with kernel-stab inoculation on X-axis and IPCA1 score on Y-axis obtained from the AMMI model: environments are plotted as a, b, c, ..., and genotypes as A, B, C, ..., . Points located near the center are stable.



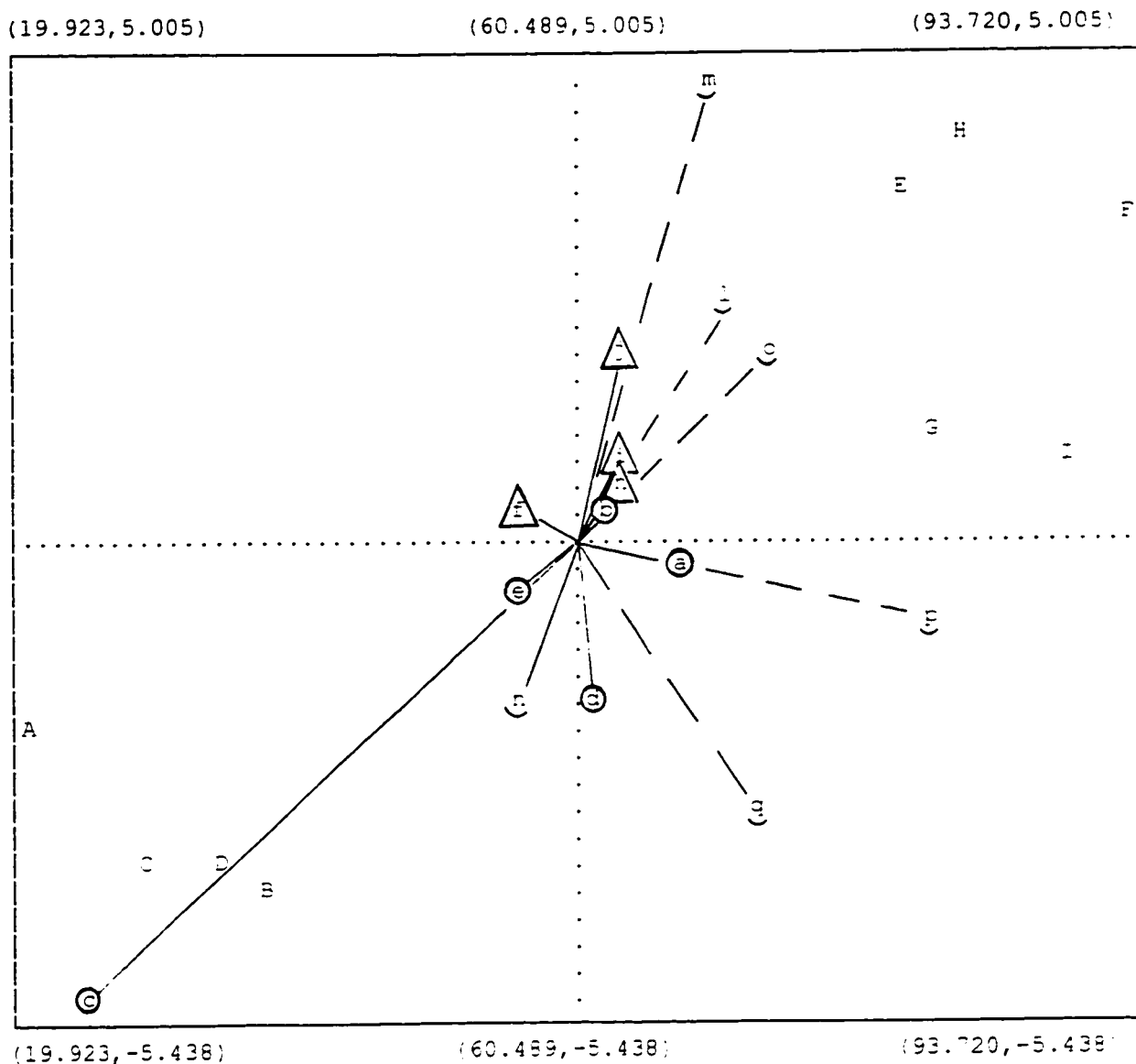
AGROBASE

Fig. 3.6a. Biplot for ear dry weight obtained with silk channel inoculation on X-axis and IPCA1 score on Y-axis obtained from the AMMI model: environments are plotted as a, b, c, ..., and genotypes as A, B, C, ... Points located near the center are stable.



AGROBASE

Figure 3.6b. Biplot for ear dry weight obtained with kernel-stab inoculation on X-axis and IPCA1 score on Y-axis obtained from the AMMI model: environments are plotted as a, b, c, ..., and genotypes as A, B, C, ..., . Points located near the center are stable.



AGROBASE

rainfall in September (RN3), see Table 3.16. September rainfall accounts for 24% of the variance encountered in ear rot ratings observed across genotypes with the silk channel inoculation, whilst the number of days with high relative humidity in August (HUM2) accounts for 28% of ear rot rating variation observed with the kernel-stab inoculation. Similar correlations were also found between dry weight and rainfall in September with both inoculation methods that accounted for 23% of the variation. These correlations suggest that weather patterns had an effect across environments and could be involved in the genotype by environment interactions.

A multiple regression analysis was computed by taking the best two weather factors, out of a total of nine, that were associated with ear rot ratings and dry weight (Table 3.17). These regressions show that 50% of the ear rot rating variation can be explained with variation in September rainfall and either the number of cool and wet days in August (COL2) or the number of days with high relative humidity in August (HUM2), for silk channel and kernel-stab inoculations, respectively. Dry weight is also consistently associated with COL2 and HUM2 across both inoculation methods, and these regressions explain 40% of the variation across environments. Therefore, changes in the environment across years appear to contribute to the variation in disease severity and possibly to the genotype by environment interactions.

3.4.7.1 Weather effect on genotype x environment interaction

In an attempt to link weather variables with the genotype x environment interaction, the environmental scores obtained in an AMMI analysis performed across both inoculation methods were regressed on the weather variables most closely associated with ear rot. The first IPCA1 score obtained with ear rot ratings was significantly correlated with September rainfall ($r=0.82$, $p<0.001$, $n=17$) and the second IPCA2 was correlated with the number of cool and wet days in August and September (Table 3.18). These results are consistent with earlier findings done with comparative methods to incorporate weather variables in GE interactions (Van Eeuwijk and Elgersma 1993).

Table 3.16. Correlations between environmental factors during July-September number of cool and wet days (COL); number of days with high relative humidity (HUM); monthly rainfall (RN), and 1) ear rot rating, 2) dry weight across 17 environments.

Variables	July (1)	August (2)	September (3)
<i>silk channel inoculation</i>			
a) Ear rot			
COL	0.048 0.85 §	-0.350 0.17	0.124 0.64
HUM	0.196 0.50	0.121 0.68	0.154 0.60
RN	0.380 0.13	-0.220 0.40	0.493* 0.05
b) Dry weight			
COL	0.035 0.90	-0.416 0.10	-0.212 0.42
HUM	-0.007 0.98	-0.433 0.12	-0.059 0.84
RN	0.198 0.45	-0.139 0.59	0.472 0.07
<i>kernel-stab inoculation</i>			
c) Ear rot			
COL	-0.066 0.80	0.280 0.28	0.170 0.51
HUM	0.208 0.48	0.525* 0.05	0.131 0.66
RN	-0.049 0.85	0.278 0.28	-0.503* 0.05
d) Dry weight			
COL	0.074 0.78	-0.479* 0.05	-0.254 0.33
HUM	-0.053 0.86	-0.335 0.24	-0.171 0.56
RN	0.115 0.66	-0.040 0.88	0.484 0.06

§ probability level; * significant at the 0.05 probability level.

Table 3.17. Multiple regression analysis between environmental factors during July-September; number of cool and wet days (COL*); number of days with high relative humidity (HUM); monthly rainfall (RN), and a) ear rot rating, b) dry weight.

Regression equations	R-square	P
<i>silk channel inoculation (n=17)</i>		
Ear rot rating = $3.084 + 0.004(RN3) - 0.079(COL2)$	0.486	(P < 0.036)
Dry weight = $126.991 - 2.818(COL2) - 1.533(HUM2)$	0.400	(P < 0.078)
<i>kernel-stab inoculation (n=17)</i>		
Ear rot rating = $3.154 - 0.006(RN3) + 0.059(HUM2)$	0.509	(P < 0.029)
Dry weight = $116.520 - 1.067(HUM2) - 3.085(COL2)$	0.400	(P < 0.081)

* July =1, August =2, and September =3.

Table 3.18. Weather factors with best two linear correlations to environmental scores of AMMI-axis 1 (IPCA 1) and 2 (IPCA 2) across genotypes and both inoculation techniques.

	First and second highest correlated variable	r	P
IPCA 1	Rainfall in September	0.82	(P<0.001)
	Cool days in August	-0.35	(P<0.180)
IPCA 2	Cool days in August	0.52	(P<0.039)
	Cool days in September	0.52	(P<0.039)

IPCA1 and IPCA2= modified principal component analysis scores .

Therefore, we can say that a good part of the genotype by environment interaction is related to weather variables, such as the amount of rainfall observed in September and to a lesser extent the number of cool days in August and September. However, the performance of the AMMI model was not as good as the joint regression model as expressed by the percentage of the genotype by environment interaction explained by each statistical model.

3.5 Conclusion

In conclusion, the different methods used in this study to investigate causal relations between genotype by environment interactions and the adaptability of genotypes according to their resistance to gibberella ear rot and yield expression have brought forward some important points.

Dry weight was significantly reduced by 41-60% over ear rot ratings ranging between 3.0 and 3.5 when the kernel-stab inoculation technique was used. This shows the potential damage that gibberella ear rot can do to maize. Moreover, the stability of resistance appears to be better for inbred lines compared to hybrids across the 17 environments under investigation. Inbred CO325 was the best performer among inbred lines for both disease resistance and yield.

The joint regression model was able to assess the environmental heterogeneity of ear rot ratings. It accounted for 27% and 36% of the total genotype by environment interactions obtained with the silk channel and the kernel-stab inoculation techniques, respectively. This heterogeneity was only 10% under natural infection levels. The heterogeneity between genotypes accounted for 57% and 47% of the interaction with each inoculation technique, leaving the unexplained interaction at only 17% across inoculation methods.

The AMMI model was able to capture only 58% of the interaction across both inoculation methods, compare to 84% for the joint regression model. However, the AMMI

model gave additional visual information with the biplot diagram constructed with the first level of the principal component analysis or IPCA1 score. This diagram shows the difference that exists between the environments in term of their interactions on the expression of resistance of genotypes to gibberella ear rot. It shows in particular that trials located in Ottawa at the Central Experimental Farm, St-Polycarpe, and Cobden have the largest interaction between genotype and environment.

Weather patterns suggest that 50% of the variation observed in ear rot ratings can be explained by the amount of rainfall in September. It shows also that the number of cool and wet days observed in August was more critical for silk channel inoculation, whilst the number of days with high relative humidity was more important to achieve severe ear rot in maize with the kernel-stab inoculation technique. Therefore, it is easier to simulate an ideal weather condition for ear rot infection with the kernel-stab inoculation method by using aerial irrigation.

CHAPTER IV

SPATIAL DISPERSAL OF GIBBERELLA EAR ROT IN MAIZE FROM A SMALL AREA INOCULUM SOURCE

4.1 INTRODUCTION

Artificial ecosystems found in agricultural areas change rapidly as new cultural practices are implemented to maximise crop performance and reduce production costs. These changes can induce new stresses which break the delicate balance found in nature as host plants are set in different conditions that may have an impact on their ability to defend themselves against pests (Real 1996).

Epidemics of fusarium head blight in wheat (*Triticum aestivum* L.) are recurrent in Canada since the 1940's (Sutton 1982). Crop damages in winter wheat have been important in Ontario as recently as 1996. Fusarium ear rot incidence in maize (*Zea mays* L.) is on the rise as well. Gibberella ear rot, a form of fusarium ear rot, is a serious disease caused by *Fusarium graminearum* Schwabe [sexual state : *Gibberella zeae* (Schwein. Petch)] on maize in many parts of the world and in eastern Canada (Chiang *et al.* 1987; Mesterhazy 1982; Palaversic *et al.* 1991; Sutton 1982).

Gibberella ear rot has economic implications because it can lead to grain contamination with mycotoxins, such as deoxynivalenol and zearalenone (Miller 1994). These mycotoxins, when present in feeds, can reduce livestock growth and performance, especially in swine (*Sus scrofa*). Gibberella ear rot epidemics are sporadic, associated with high consecutive days of rainfall and cool temperatures (20-25° C) but they are also recurrent in eastern Canada (Sutton and Konga 1986; Vigier *et al.* 1997).

Fusarium graminearum can be propagated through macroconidia or ascospores that are deposited on debris from previous agricultural crops, such as maize, wheat (*Triticum sativum*), and barley (*Hordeum vulgare* L.). These propagules can infect maize ears and induce mold growth on kernels or they can remain dormant in the soil for many years as saprophytic mycelium or resting chlamydospores if they do not find any host plants (Parry *et al.* 1995). These propagules are believed to be mostly dispersed by rain-splash and wind gusts (Sutton and Konga 1986).

Disease distribution in a host plant population is not expected to be random and field studies indicate that infected plants usually occur as clusters within a larger population (Real *et al.* 1992). These findings are corroborated by many plant epidemiologists (Campbell and Madden 1990; Van der Planck 1982; Zadocks and Schein 1979). It is not known how gibberella ear rot spreads from these clusters to entire fields. It is also not clear how environmental conditions and agronomic practices affect this spread.

Agronomic practices in eastern Canada tend to promote the use of high plant densities in maize with narrow rows to increase yields (Scheifele *et al.* 1996). New genetic material, such as dwarf stature maize could make this practice feasible in the near future. Disease spread could be more critical as plant row spacings decrease making it easier for plant pathogens to transmit from one plant to another. However, an increase in plant population can also decrease the distance travelled by air-borne propagules (Minogue 1986). Therefore, it is imperative to study the effect of plant row spacings and the micro-climate as it can influence the rate of spore dispersal and the severity of the disease.

4.1.1 Approaches in studying phytopathological systems

The movement of biotic agents such as bacteria, viruses and fungi is of special interest to epidemiologists. Plant disease epidemics require an understanding of the conditions that promote pathogen reproduction and spread into disease-free areas. Fungal diseases, in particular, have two major means of dispersal: (1) motile spores which are either asexual or sexual propagules can multiply in a variety of conditions and can also be

dispersed by air, rain-splash or through the soil if they are soil-borne; motile spores can also spread through the contact of healthy plants with infected ones by mycelium. The mode of dispersal of *Fusarium graminearum* inoculum has not been fully identified, but many possibilities have been proposed (Parry *et al.* 1995).

4.1.1.1 Disease spread and spore dispersal

The behaviour of a disease epidemic in its development in agriculture or in nature is better understood starting from a disease free environment, where a point source of infection is applied (Jeger 1985). A disease expanding from a source can be monitored and the interaction of pathogens, diseased tissue, and visual damage in a field can be measured through simulated conditions. The spatial disease spread in relation to spore dispersal can be studied in actual field conditions.

There are different components that have been identified to describe disease gradients (Leonard and Fry 1986; Minogue 1986). The dispersal gradient is the first step that describes the number of spores or propagules that are deposited on plants as a function of distance from an infection source. Later, an infection can occur according to the susceptibility of the host and results in an infection gradient. Disease spreads which depend on a primary infection are associated with monocyclic diseases and those which depend on secondary infection gradients are associated with polycyclic diseases.

Little is known about *Fusarium graminearum* dispersal in a field situation and how plants are infected with ear rot. It is hypothesized in the present study that weather conditions and plant population variation achieved with two row spacings have an effect on ear rot infection when a *Fusarium graminearum* inoculum source is applied from a point source of inoculation. It is assumed that it is possible to develop a disease spread model over a short distance even in years with large background infection levels from other *Fusarium* spp. in the field.

An attempt was also made to collect propagules from the same inoculum source to

monitor the effect of wind direction and distance from the source on spore dispersal.

4.2 MATERIALS AND METHODS

4.2.1 Field plot description and experimental design

In 1995 and 1996, field studies were carried out on an Uplands sandy loam soil type (Canadian Soil Classification System) at the Central Experimental Farm in Ottawa (45° 22' N, 75° 43' W). The field had a 2% slope in a southern direction. Plot dimensions were 10 x 10 m consisting of 10 rows in an east-west direction spaced 0.90 m apart for single rows and 20 rows spaced 0.45 m apart for the narrow rows with 50-60 seeds per 10m row. A total of 16 plots were arranged in a randomized complete block design with four replicates distributed across the slope. Treated plots were seeded with a very susceptible maize inbred line, CO266, to maximise disease infection response (Reid *et al.* 1992). Each plot was bordered with buffer plots of identical size and planted with a standard commercial hybrid with moderate susceptibility to gibberella ear rot.

Plots were subdivided in five sections or quadrants that were 5m x 5m in size according to row orientations in the NW, SW, SE, NE directions, and in the centre of the plot. Each replication block had a 5 m clearing on each side for access and weed control using recommended herbicides. Treated plots were inoculated one week prior to the maize early silking period (R1 on Ritchie's scale) during the first week of August, taking into account that peak infection period for inbred line CO266 is 3 days after early silking (Ritchie *et al.* 1986; Reid *et al.* 1992b).

4.2.2 Preparation of inoculum and inoculation method

The artificial inoculation source consisted of a 40 ml (5×10^5 macroconidia/ml) suspension of one *Fusarium graminearum* strain (DAOM180378) registered in the National Fungus Collection of Agriculture and Agri-Food Canada. The suspension was mixed and incubated for 10 days with a 1,250 ml volume of pre-soaked and twice sterilized maize kernels in 20-minute cycles in 1.89-litre glass Mason jars. These jars were put flat on an incubator bench and rotated every two days under daylight and UV fluorescent tubes at

25°C and with a 12-hour light cycle. Each jar was air ventilated with a synthetic filter disc (Fungi Perfecti, Olympia, WA) installed in the metal lid with a 2 cm perforation to prevent contamination. After the incubation period, mycelium covered maize kernels were spread on the soil surface in a 1 m diameter area. Control plots consisted of a 1 m diameter bare soil area in the centre of each plot. In 1996, the inoculum source was covered by a 0.015 m wire mesh open end cylinder laid 0.15 m over the soil surface to prevent bird feeding on the maize inoculum.

4.2.3 Plant growth and disease measurements

Data were collected at plant maturity on plant height, population, and leaf area. Trials were harvested by hand in mid-October to measure kernel dry weight on primary ears. Disease ratings were assessed before harvest using an ear rot rating scale ranging from 1 to 7 (Bolton *et al.* 1990; Reid *et al.* 1996). Disease incidence was calculated as a percentage of ears with ratings of 2 and more. A total of ten rows per plot were sampled for disease, alternate rows were sampled in narrow-row plots. Ratings were recorded on alternate plants on the row. Analysis of variance was performed using SAS PROC GLM and treatment response was tested for separation with the Duncan's multiple range test (Steel and Torrie 1980). Ear rot ratings were also matched with kernel and silk samples to identify *Fusarium* species.

4.2.4 Propagule collection and identification

Spore traps were constructed to provide an effective method to measure the volume of air-borne spores. Initially, the Burkard jet spore trap was intended for the spore capture because it has shown good potential with air-borne propagules of *Fusarium* species (Martin 1988). However, this trap collects spores in large numbers and over a large area, and is very expensive when many units are required. For the purpose of this study, it was assumed that *Fusarium* air-borne propagules were not the main source of infection but rather the propagules dispersed at maize ear height levels by wind gusts or rain-splash coming from the inoculant source applied on the soil surface. Therefore the idea of an artificial plant that would act as a spore trap was close to reality and affordable. This

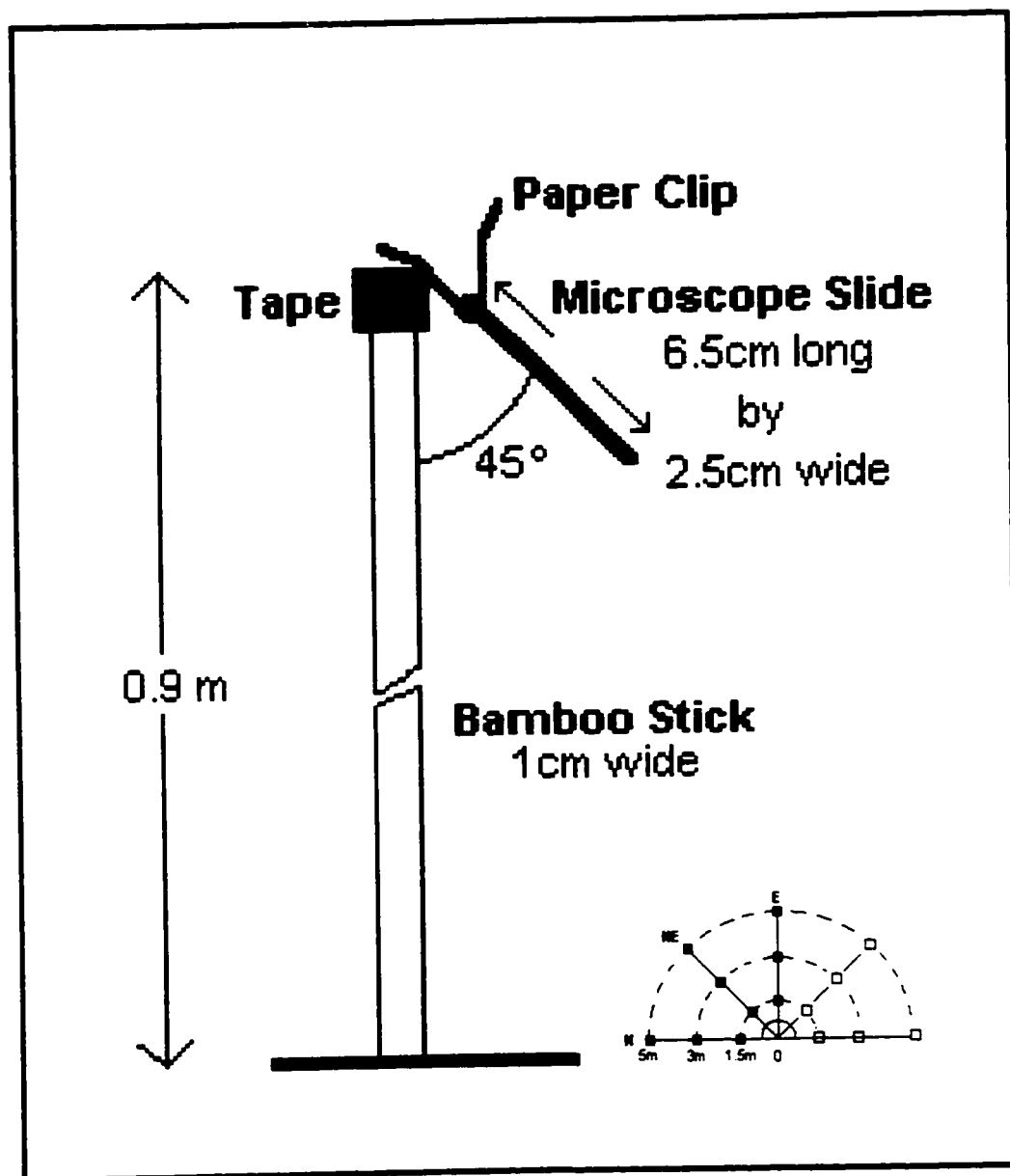
individual spore collector consisted of a bamboo stick with a microscope slide attached with a paper clip at maize ear height or 0.90 m above ground. Spore collections were done at different dates after inoculation on sticky petroleum jelly coated slides fixed at a 45° angle below the horizontal (Fig. 4.1).

A series of nine spore traps on bamboo sticks were installed in a fan shape in the north, north-east and, eastern directions at 1.5, 3 and 5 m from the source. New sets of slides were placed in the afternoon and collected about 40 hours later in the morning to benefit from the two consecutive peak propagule release periods that occur in late evening and early morning (Paulitz 1996). Collections were made once a week over a period of four weeks and *Fusarium* propagules were identified and counted under a microscope referring to known shapes of *G. zeae* ascospores, i.e. the sexual propagules of *F. graminearum* (Nelson et al. 1983). After collection, slide traps were dyed with a lactophenol trypan-blue solution (Plant Pathologist's Pocketbook, Commonwealth Mycology Institute 1968) and stored at 2°C. They were visually scanned for presence of ascospores under a microscope (100X) according to distinctive shape and septation.

4.2.4.1 Collection at the inoculum source

In 1996, additional spore dispersal data were collected in micro-plots 3 x 3 m in size planted with the same CO266 inbred line in wide rows. This small scale study was done in an attempt to measure more accurately the latent period before sporulation and narrow down the spectrum of teleomorphic *F. graminearum* propagules collected near the soil surface. Three inoculum rates were applied over micro-plots, corresponding to 0, normal (110 ml), and double inoculum (220 ml) rates of maize kernel inoculum applied in the main experiment. The inoculum was applied on the centre of each small plot on approximately 0.1m² area which was covered with a 1.5 x 1.5 cm² wire mesh to protect from bird-feeding.

Fig. 4.1. Spore collector on bamboo stick with a standard microscope slide coated with petroleum jelly and diagram for placement in the field from an inoculum source.



The lay-out of the plots was arranged in a completely randomized block design with 3 replications without border rows. Perithecial formation was visually recorded and ascospore discharge measured. Slide traps were attached 0.20m above the soil surface on top of the inoculum source in four directions. Spore collection was done between 6 and 28 days after inoculation, and results were reported as the number of ascospores per slide-day, starting on August 4, 1996.

4.2.5 Environmental factors

Daily rainfall, temperatures, and cumulated wind speed records were monitored at a weather station located within 400 m of the field study over a five-week period after inoculation in 1995 and 1996.

4.2.6 Yield and plant growth measurements

Plant populations were estimated on three random sub-samples over a 4 m² area, plant height on five plants. Grain yield was estimated at the end of the R-5 stage from the total ear weight collected on three sub-samples over a 2m² area. Leaf areas were measured on three random plants per replicated plot at the vegetative stage maturity (R4 on Ritchie's scale), measurements of maize leaf area were taken according to Dwyer and Stewart (1986).

4.2.7 Spatial distribution pattern analysis

Spatial pattern analysis was conducted to provide quantitative information on the propagule dispersal (Campbell and Madden 1990). Ear rot spatial patterns were evaluated according to two classes: random and aggregated. A random pattern indicates an independent dispersion where no individual can influence any other in any way, and an aggregated pattern reflects the patchiness or clustering of the disease and the presence of one individual being influenced by another, indicating there is some "foci" development as expressed by epidemiological terminology. Pattern analysis was achieved by counting the number of consecutive infected plants among a set of rows and intra rows forming a

matrix or quadrant. The doublet analysis used to identify these patterns is described by the following equation (Vanderplanck 1946; Vanderplank 1960):

$$E(D) = (m(m-1))/nN, \quad (\text{Eq.1})$$

where:

$E(D)$ is the maximum number of expected doublets on a row to assume randomness, m = number of infected plants, N = number of plants in the row, n = number of rows. If the observed number of doublets is greater than expected, we can assume aggregation of diseased plants.

If aggregated patterns were found with the presence of *F. graminearum* isolates, a contour mapping technique was used for representing isolines or gradients of disease rating following a distance-based method called the nearest neighbour method (Watson 1994). However, this method was used assuming a maize plant can occupy any location in a row crop such as maize.

4.2.8 Spore dispersal, disease spread, and models

Disease spread in host plant populations is generally associated with a source of infection and it is expected that plants with the most severe levels of infection will occur around a source from which it will spread in some form of aggregation in different directions according to prevailing winds or the movement of secondary infection vectors such as insects or birds (Vigier *et al.* 1997). Disease spread and spore dispersal occur in two forms: (1) a “wave-like” shape of infected plants radiating from a source and progressing in the field; (2) a “non-wave” pattern of separate events of infection that are described as “disease foci” (Minogue 1989). The wave-like dispersal follows simple diffusion theory but the foci dispersal follows an exponential shape where the disease rating is inversely proportional to a power of the distance from the inoculation source. Foci dispersal is more suited with *Gibberella zeae* ascospores as observed in earlier studies on wheat head blight (Paulitz 1996; Fernando *et al.* 1997).

The shape of the spore dispersal and disease spread can be influenced by external factors such as wind direction around the inoculum source at critical infection stages. Therefore measurements were taken according to prevailing wind directions. Spore counts were measured with bamboo stick spore traps located at different distances from the source assuming that the monthly prevailing seasonal (June to September) wind direction was from the south-west according to historical wind data from the Central experimental Farm, Ottawa, Ontario.

4.2.8.1 Power Law Model for disease spread

The Power Law model assumes that disease rating (y_i) of a susceptible host plant is inversely proportional to a power of the distance from an inoculation source (X) (Gregory 1968). The disease spread obtained with the Power model equation is:

$$Y_i = ax^{-b}, \quad (\text{Eq. 2})$$

or in its linear form, considering that small datasets of disease incidence follow a binomial distribution, the equation becomes:

$$\text{Ln}(y_i) = \text{Ln}(a) - b \cdot \text{Ln}(x) \quad (\text{Eq. 3})$$

where:

a = Y_i -intercept, x = distance from the inoculum source, and b = slope of the disease spread from the origin of the inoculum source or the unit less spread parameter.

4.2.8.2 Exponential Model for disease dispersal

The exponential model is a variation of the Power model (Kiyosawa and Shiyomi 1972) and it assumes that ' Y_i ' is inversely proportional to an exponential function of ' x '. It is expressed by the equation:

$$Y_i = C e^{-dx}, \quad (\text{Eq. 4})$$

which can also be expressed by its natural log transformation:

$$\text{Ln}(Y_i) = \text{Ln}(C) - dx \quad (\text{Eq. 5})$$

where:

'C' is the maximum disease level at the source, 'd' is a measure of the gradient steepness similar to the Power Law model, but in this case, it is not affected by the origin of the inoculum source, but it is calculated from the half-distance (d_{50}) at which disease level is reduced by 50%, or $d_{50} = 0.693 \cdot h.d.$ (Fitt *et al.* 1987). Both models are evaluated with a linear regression model for fitness and a coefficient of determination (R^2) for significance.

These two empirical models, as compared to long distance diffusion models, do not predict dispersal over long distances but they are better suited for the estimation of various fungal disease spread over a few hundred meters distance from an inoculum source (Fitt *et al.* 1987).

4.3 RESULTS AND DISCUSSION

4.3.1 Yield and plant growth measurements

Plant populations in narrow rows were 81,000 and 69,000 p/ha in 1995 and 1996 in control plots, respectively, while wide rows had 46,000 and 43,000 plants/ha (Table 4.1). The leaf area index, which is a measure of the amount of foliage surface per unit of soil area was 35% and 69% higher with the narrow row spacing compared to wide rows in 1995 and 1996, respectively. Mean grain weight per m^2 was not significantly different between the two row spacings despite the increase in plant population achieved with the two types of row spacings. Plant growth parameters such as plant height, leaf area, and dry weight were positively correlated with ear rot incidence and severity in 1995 but not in 1996 (Table 4.2).

The leaf area index was significantly correlated with plant height during both years of the study showing a phenotypic variation of the tested CO266 line. Kernel weight was not significantly different across row spacings but appeared to be higher (+25%) in 1996 compared to 1995. There was no distinct plant growth effect that appeared to explain the increase in grain weight, except for environmental conditions that were substantially better

Table 4.1. Effects of row spacings on yield performance, growth factors, and ear rot incidence with a point source inoculation of *Fusarium graminearum* propagules.

Treatments	Kernel weight (g/m ²)	Ear rot		Plant population (plants/m ²)	Plant height (m)	Leaf area index
		incidence	severity (%)			
1995 trials						
Wide rows control	614.5	24.0	8.5	4.6 b	1.86	0.748
Wide rows inoculated	594.1	49.2	22.7	4.8 b	2.01	1.153
Narrow rows control	488.8	35.0	13.7	8.1 a	1.84	1.249
Narrow rows inoculated	585.4	34.5	11.2	7.4 a	1.84	1.323
Mean	570.7	35.7	14.0	6.2	1.89	1.118
F-value	NS	NS	NS	**	NS	+
1996 trials						
Wide rows control	700.3	33.3	9.8	4.3 b	1.82	1.136 b
Wide rows inoculated	541.0	33.3	9.2	4.2 b	1.85	1.088 b
Narrow rows control	864.5	35.3	9.8	6.9 a	1.83	1.810 a
Narrow rows inoculated	754.0	32.2	10.1	7.7 a	1.82	1.955 a
Mean	715.0	33.5	9.7	5.7	1.84	1.497
F-value	NS	NS	NS	**	NS	**

NS =non significant differences between treatments; + = differences between means at the 0.10 level.

** = significant differences at the 0.01 level.

Table 4.2. Correlations between plant growth parameters and ear rot.

Plant growth parameters	Ear rot		Height	Population	Leaf Area index
	Incidence	severity			
1995 trials					
Height	0.708**	0.734**			
Population	—	—	—		
Leaf area	0.639**	0.546*	0.615**	—	
Dry weight	0.520*	0.408+	0.457+	-0.411+	—
1996 trials					
Height	—	—			
Population	—	—	0.560*		
Leaf area	—	—	0.656**	0.896**	
Dry weight	—	—	—	0.457+	0.409+

Levels of correlation significance: — = none, + = 0.10 level; * = 0.05 level; ** = 0.01 level; n=8.

in 1996, with no limitation in rainfall.

4.3.2 Ear rot incidence and severity

Ear rot incidence levels were similar during both years of the trial with an average of 35% of plants showing symptoms of ear rot. Ear rot levels appeared to be lower in control plots in 1995 compared to treated plots, but this difference was not significant. In 1996, both control and treated plots had the same level of infected plants suggesting that background inoculum levels of infection were very high during that year and could have masked the net effect of the inoculum source. Variation across replicates was too large even when a logarithmic transformation was applied on these data. *Gibberella* ear rot index and its severity were positively correlated with plant growth parameters such as plant height, leaf area, and grain weight in 1995, but this trend was not confirmed in 1996. These results show the difficulty encountered with disease simulation in the field where background infection is present.

4.3.3 Identification of *Fusarium* species

There were eight *Fusarium* species identified on silks and kernels in both control and inoculated plots (Table 4.3). The number of *F. graminearum* isolates identified on silks in mid-August appeared higher during both years, but it was much lower on kernels sampled in early October compared to other *Fusarium* species. It is reasonable to say that the presence of *F. graminearum*, with all strains confounded, was higher in mid- August on the silks but was later overtaken by other *Fusarium* species in early October, as observed on kernel samples. Other *Fusarium* species, such as *F. avenaceum*, *F. semitectum*, and *F. subglutinans* were more virulent background species that could be responsible for the disease incidence observed mainly in control plots where *F. graminearum* was not found.

Table 4.3 . Number of *Fusarium* species isolates identified on mature silks (Aug.19, 1995 and Aug. 22, 1996) and kernels (Oct. 5, 1995 and 1996) across all plots.

<i>Fusarium</i> species	-- narrow row spacing --				--wide row spacing --			
	Inoculated		control		Inoculated		control	
	S	K	S	K	S	K	S	K
1995 trials								
<i>F. graminearum</i>	7	2	1	1	10	2	2	0
<i>F. moniliforme</i>	0	0	1	5	1	5	1	2
<i>F. subglutinans</i>	1	3	1	3	9	8	0	5
Other <i>F.</i> species*	3	15	2	21	2	26	3	9
1996 trials								
<i>F. graminearum</i>	10	0	7	0	7	0	5	0
<i>F. moniliforme</i>	0	0	0	1	0	0	1	0
<i>F. subglutinans</i>	6	6	5	1	5	6	4	1
Other <i>F.</i> species	1	15	4	18	2	11	3	22

* Other *Fusarium* species = *F.equisiti*, *F.avenaceum*, *F.sporotrichioides*, *F.semitectum* and *F.sambucinum*; S=silk, K=kernel.

4.3.4 Spatial distribution and aggregation

In 1995, the spatial distribution of *F. graminearum* isolated from silks and kernels recorded per quadrat and the distribution of infected plants were analysed to find out if prevailing wind directions had an effect on infection parameters.

4.3.4.2 Spatial distribution of ear rot rating

The Van der Planck "doublet" method used to measure the level of aggregation of all infected plants in directional quadrants reveals that 13 out of 16 plots had some quadrants with aggregation of infected plants in 1995, but only 7 plots had some aggregation in 1996 (Figs. 4.2 and 4.3). The higher number of aggregated quadrats was not associated with inoculation because aggregation of infected plants occurred also in control plots. Overall aggregation of diseased plants occurred more often in northern direction quadrats which can be associated with August SW prevailing wind but was not associated with the seasonal south-westerly prevailing wind as observed after inoculation in August during both years. The observed increase in aggregation was confirmed with a significant increase in ear rot incidence in the NW and SE quadrants with inoculated narrow rows (45cm) compared to NE quadrants which had less infected maize ears (Table 4.4).

4.3.5 Ascospore sampling at the source in time

Mature *G. zeae* ascospores and *F. graminearum* macroconidia were detected in very small amounts, in a separate experiment carried out in small plots where slide traps were set just above (0.2 m) a maize inoculum source in 1996 (Figs. 4.4 and 4.). The presence of macroconidia even at eight and 18 days after inoculation was sporadic. However, a large quantity of *Alternaria* spp. ascospores, as identified in petri dish cultures, were found on the slide collectors showing slide traps were operational (Figs. 4.6 and 4.7). The association between the number of days after inoculation at four sampling dates from 4 to 26 days and the number of *Fusarium* propagules collected on slide traps could not be done because very few were identified. However, the number of *Alternaria* ascospores during the same period was high and could be associated with rainfall.

Fig. 4.2. Aggregation of ear rot in five 5m x 5m quadrants (NE, SE, SW, NW and center) at harvest time in 1995.

Figure 4.2. Aggregation of ear rot in five 5m X 5m quadrants (NE, SE, SW, NW, C) at harvest in 1995.

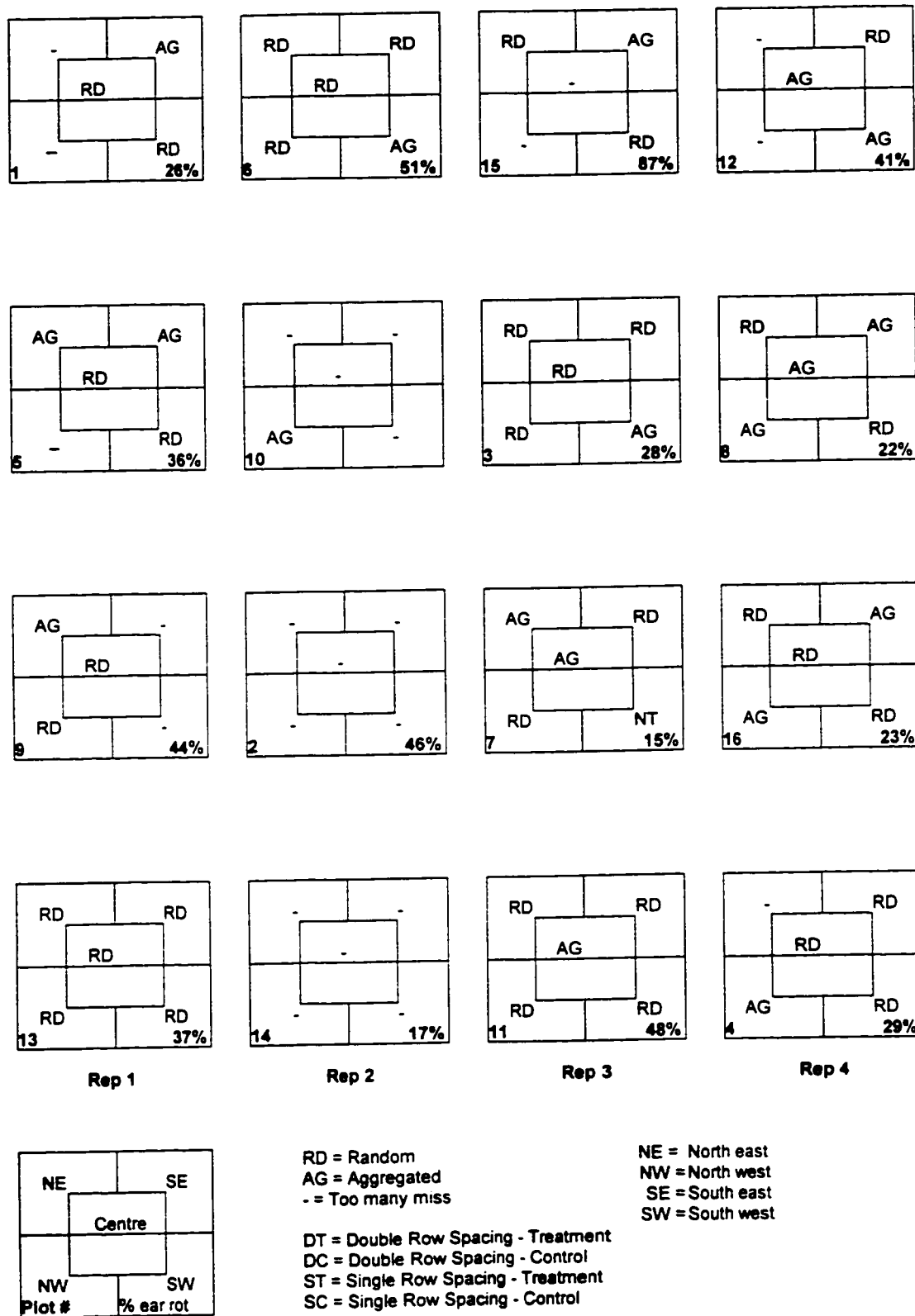


Fig. 4.3. Aggregation of ear rot in five 5m x 5m quadrants (NE, SE, SW, NW and center) at harvest time in 1996.

Figure 4.3. Aggregation of ear rot in five 5m X 5m quadrants (NE, SE, SW, NW, C) at harvest in 1996.

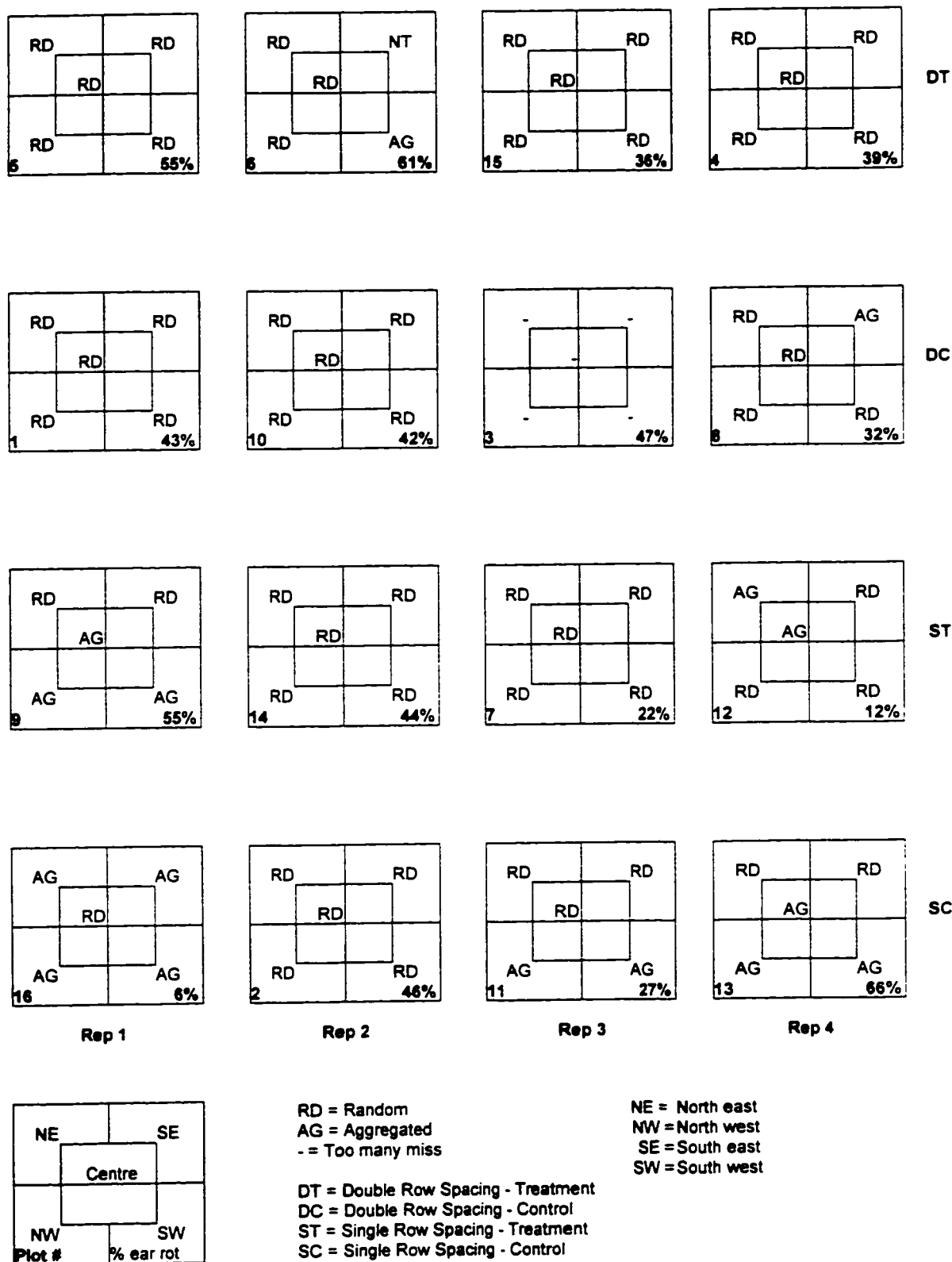


Table 4.4. Relationship between ear rot incidence (%) and direction from the inoculum source in five 5 x 5 metres quadrats.

Treatments	—narrow row spacing—		—wide row spacing —		P
	Inoculated	control	Inoculated	control	
1995 trials					
NW	12.8 a	13.0	22.2	8.9	0.97
SW	12.0 a	11.1	16.5	11.6	0.90
SE	9.9 a	7.9	12.0	2.5	
NE	2.2 b	12.0 a	27.1 a	4.0 ab	0.04
Centre	9.0 a	8.6	28.1	7.3	0.54
P	0.05 *	0.59	0.59	0.19	
1996 trials					
NW	10.1	13.6	6.5	6.9	1.00
SW	13.0	12.4	10.1	8.0	0.43
SE	5.8	6.6	12.5	5.8	
NE	7.6	12.2	8.7	7.5	0.63
Centre	14.8	12.4	8.2	5.5	0.15
P	0.34	0.32	0.63	0.45	

* Significant differences at the 0.05 level, based on analysis of variance on transformed ear rot incidence data= Ln (fusarium ear rot incidence +1).

Fig. 4.4. *Fusarium graminearum* macroconidia (bar = 40 μ m) observed under a microscope on a spore collector placed just above a maize inoculum source in a micro-plot.

Fig.4.4

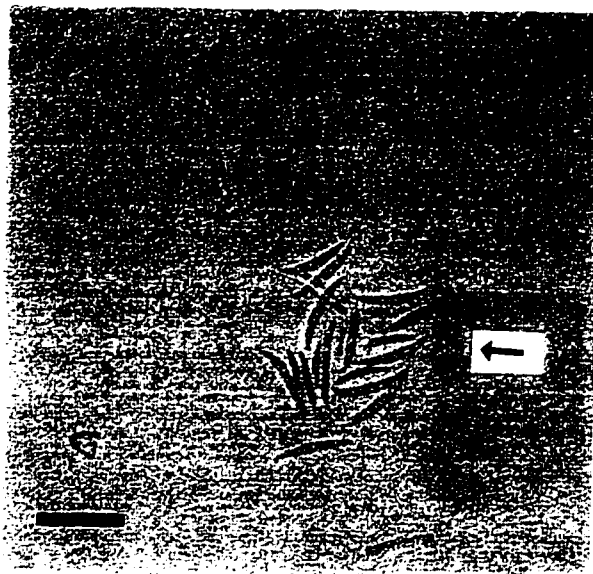


Fig. 4.5. *Gibberella zeae* ascospores (bar = 60 μ m) observed under a microscope on a spore collector placed just above a maize inoculum source in a micro-plot.

Fig. 4.5

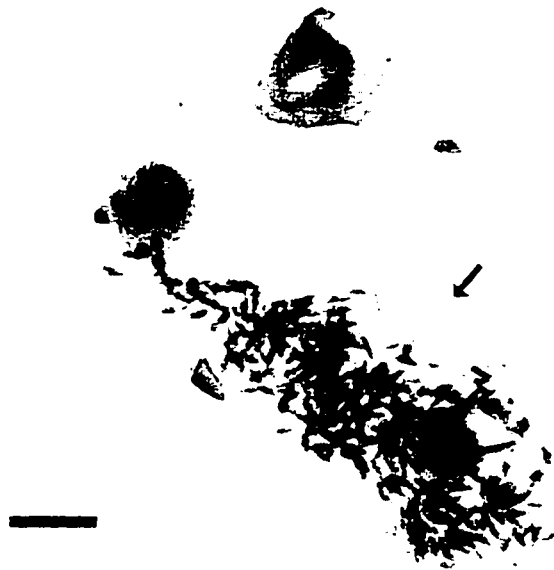


Fig. 4.6. *Alternaria* spp. ascospores (bar = 40 μ m) formed in a chain observed under the microscope on a spore collector placed just above a maize inoculum source in a micro-plot

Fig. 4.6

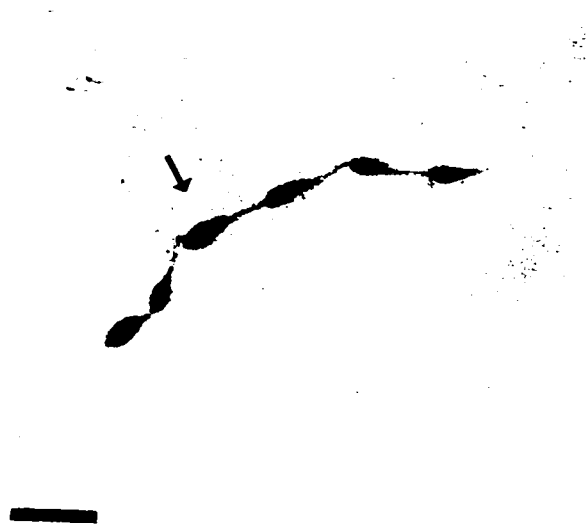
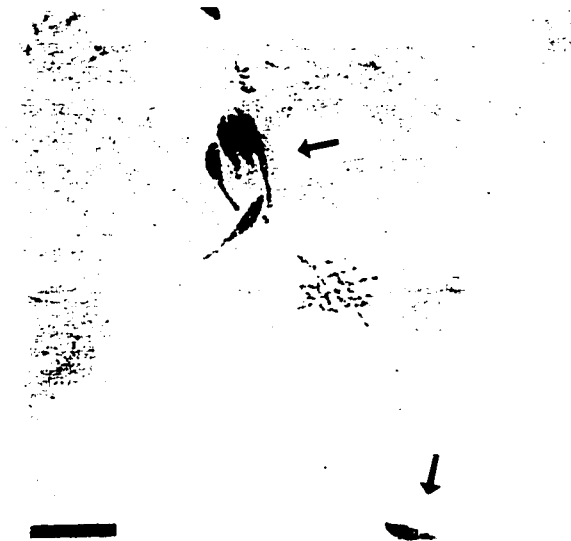


Fig. 4.7. Various *Alternaria* spp. ascospores (bar = 40 μm) observed under the microscope on a spore collector placed just above a maize inoculum source in a micro-plot.

Fig. 4.7



The presence of the large number of *Alternaria* propagules collected on the micro-plots was associated mainly to rainfall and reflected mainly a background effect of the fungal mass present on the soil surface and on plant debris. *Alternaria* presence just above the maize inoculum source shows an ability of these propagules to colonize despite an established colonization by *Gibberella zeae* perithecia (Tschanz *et al.* 1976). *Alternaria* species and *Fusarium* species are both anamorphs from the Hyphomycetes fungi class and they are prime colonizers of plant debris and are very likely to be found in association (Kendrick 1985). *Fusarium* species have a phyalidic conidiogenesis with slimy conidia while *Alternaria* species have a formation in acropetal with conidia in chains with a pattern of apical growth. This latter formation could be more easily dispersed and trapped by the spore traps coated with petroleum jelly used in this study. However, the teleomorphic stage in *Fusarium* species is characterized by the presence of a perithecium from which ascospores are ejected in the air when a certain water pressure is reached. Therefore, it appears that *G. zeae* ascospore release and *F. graminearum* macrocodia, dispersal, just above an inoculum source was minimal. It is also possible that the slide traps might have offered a too small surface area to collect these spores.

4.3.6 Ascospore capture in large plots in space and at different intervals

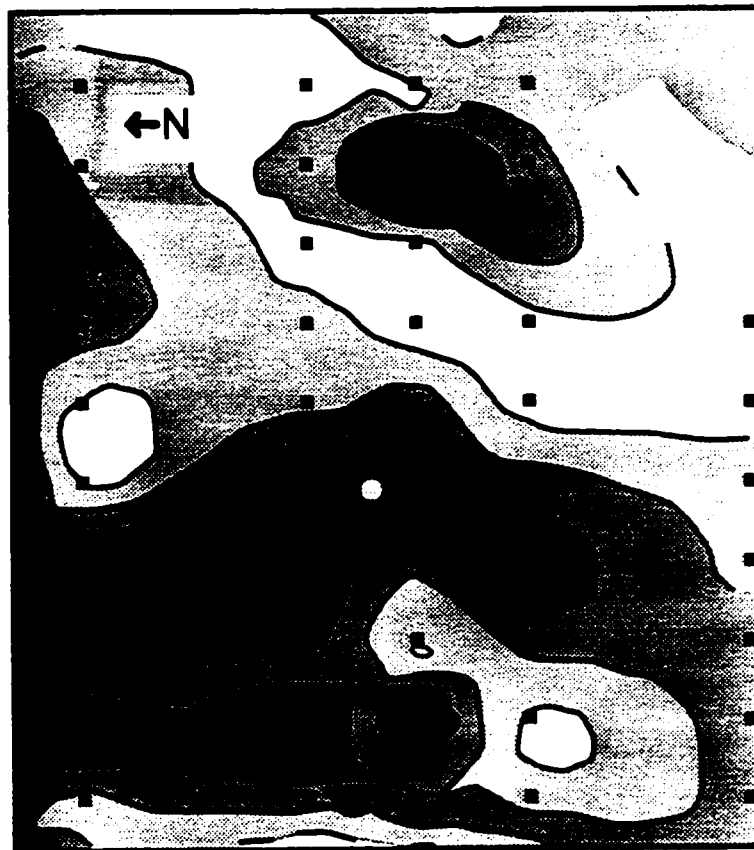
Fusarium propagule captured across narrow and wide row spacings done at three collections dates at three distances from the source and in three directions was not any better than collection done at the source in the micro-plots. Here again, *Alternaria* ascospores were present in large numbers across inoculated and control plots.

4.3.7 Contour isolines for disease spread

As observed earlier, in section 4.3.4.2, the presence of aggregation patterns on fusarium ear rot infected ears and the presence of *F. graminearum* on kernels at harvest was found on a few inoculated plots. The selected plots to be analysed with ear rot contour lines were plots 7 and 16 in 1995, and plots 6 and 12 in 1996, because they fitted the selection criteria (Figs 4.8 - 4.11). Isolines were drawn in 0.5 units increments of ear rot rating to give sufficient data for the calculation of the gradient steepness.

Fig. 4.8. Ear rot isolines (rating =1.5 to 4.5) in plot no. 7, in 1995. Wide row spacings (0.90m), disease incidence= 15%, ear rot rating=2.5.

Fig 4.8



1 2 3 4 5

1m

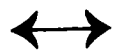
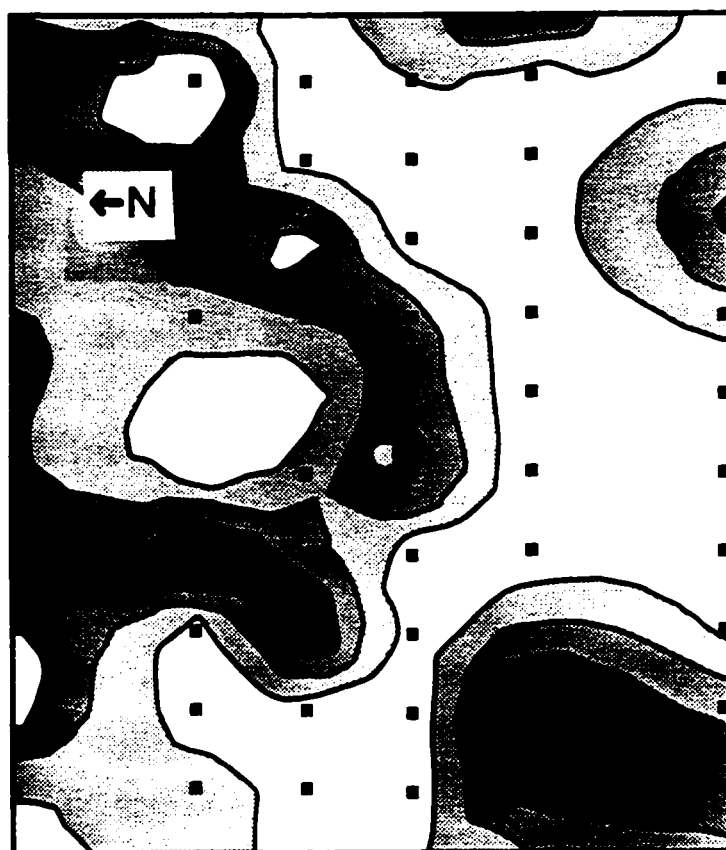


Fig. 4.9. Ear rot isolines (rating =1.5 to 4.5) in plot no. 16, in 1995. Wide row spacings (0.90m), disease incidence= 23%, ear rot rating=2.1.

Fig. 4.9



1m

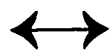


Fig. 4.10. Ear rot isolines (rating =1.5 to 3.5) in plot no. 6, in 1996. Narrow row spacings (0.45m), disease incidence= 51%, ear rot rating=2.0.

Fig. 4.10

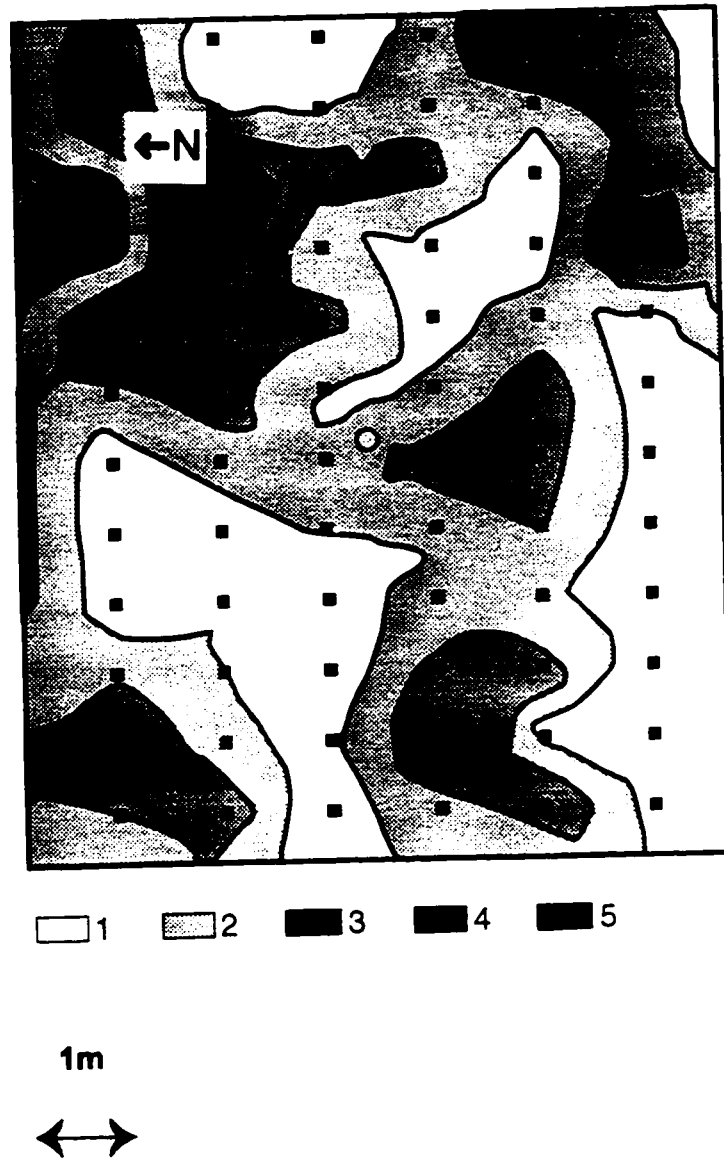
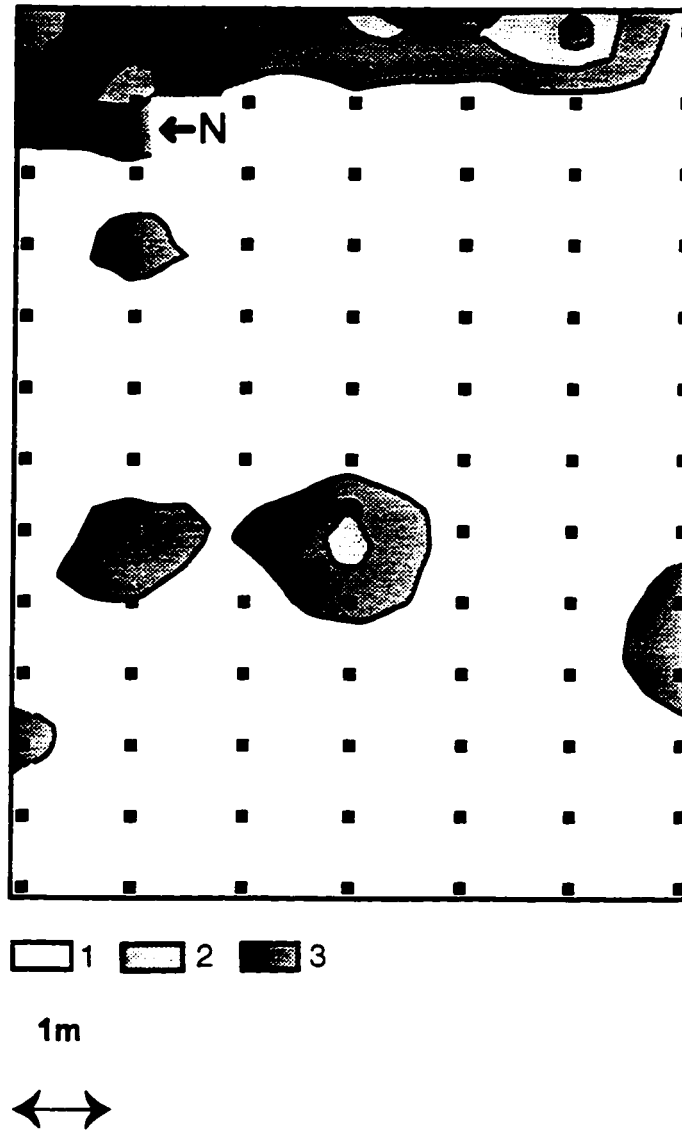


Fig. 4.11. Ear rot isolines (rating =1.5 to 3.5) in plot no. 12, in 1996. Wide row spacings (0.90m), disease incidence= 41%, ear rot rating=1.2.

Fig. 4.11



4.3.7.1 Exponential model parameters

The steepness gradient ranged from 0.43 to 0.99 m for the three plots where the exponential model fit was significant (Table 4.5). These results are comparable to earlier findings observed with fusarium ear blight on wheat (Fernando *et al.* 1997). These findings reflect the short distance covered by the disease from a small area inoculum source. Three out of the four selected plots had similar model parameters with coefficient of determination ranging from 0.45 to 0.67 ($P < 0.01$). The narrow row plot did not seem to have different model parameters compared to the wide row plots.

4.3.7.2 Power Law model parameters

The Power Law model parameters were similar for all plots and the model fit was better than the exponential model with coefficient of determination ranging from 0.38 to 0.75 ($P < 0.01$). The model fit was even significant for plot 7 which did not have a proper fit with the exponential model. Therefore it appears that the Power Law model gave a better fit for the estimation of the disease spread.

4.4 Conclusion

The study of spore dispersal and disease spread can be difficult since the simulation of a disease epidemic in a field situation is not easy to achieve. Earlier epidemiological studies concerned with ear rot in maize have focused on severity of disease infection rather than dispersal.

The Power Law model appeared to be a suitable model to predict ear rot dispersal over short distances. A similar disease spread was found for narrow or wide row spacings on plots with aggregation of diseased plants and presence of the *F. graminearum* strain on silks and kernels, showing a positive inoculation.

Changes in the expression of phenotypic character, through different row spacings were significantly achieved for leaf area index. Spore dispersal measurements were not sufficiently accurate to predict any dispersal rate or detect the duration of a latent

Table 4.5. Mean ascospore count per slide and per day over 4 directions and 3 replicates per day per slide at 0.20m above the inoculation source in 3 x 3 metres micro-plots and environmental parameters during the sampling period in 1996.

Days after inoculation	Volume of inoculum (ml/m ²)			Mean daily environmental conditions			
	0	1250	2500	Temp. °C.	Rainfall (mm)	Relative Humidity (%)	Cumul. wind (kph)
6	4.5	4.8	3.8	21.2	0.2	81.2	4.5
8	1.0	2.0	4.5	24.7	0.0	85.9	25.0
18	0.3	1.3	1.0	21.0	3.2	83.0	36.0
28	4.0	11.5	1.5	17.0	0.8	81.1	33.0

period before dispersal. The massive presence of *Alternaria* spp. ascospores throughout the study and the paucity of *Fusarium* propagules, either as ascospores or macroconidia, even just above the source shows that the spore trapping technique might not be adequate due most likely to a small trapping surface.

CHAPTER V

GENERAL CONCLUSIONS AND DISCUSSION

5.1 MAIN CONCLUSIONS

Despite the intense pressure plants are subjected to by pests, many individuals can survive because they express genetic variation that can ward off pathogens. In agricultural systems, the natural gene pool is often bypassed to favour plants that have the greatest potential to nourish mankind. In an attempt to find ways to control a particular disease such as fusarium ear rot in maize, a three-way approach was taken in this thesis. First, the disease was studied in relation to its environment; secondly, the expression of plant resistance to fusarium ear rot was studied in relation to different modes of pathogen entry in the plant across a range of environmental conditions; and finally, the disease spread was studied through changes of phenotypic expression of a particular susceptible genotype.

Fusarium pathological research encompasses twenty parasitic species that can be particularly virulent with the production of mycotoxins that are detrimental to animal and human health. Even if these fungi have been extensively studied “in vitro”, few studies have been done in agricultural conditions. Finding new insight in this context is very complex as this fungal pathogen responds to external factors that are uncontrollable. This was the challenge of the present thesis work spanning a six-year period (1991-1996).

The first series of questions addressed in Chapter II were: 1) Are fusarium ear rot symptoms expressed in the field in the early eighties are caused by the same *Fusarium* species observed in the early nineties? 2) Does disease expression appear only during years with above average rainfall, especially when maize genotypes are exposed to wet

conditions at the critical anthesis stage?, and 3) Is it possible to predict the percentage of plants infected with the disease from field observations? To address these issues, three years of sampling data have been analysed to establish a model and testing areas were chosen to verify the predictive model on independent data. The model proved to be reliable and it highlighted the fact that fusarium ear rot in the early nineties, contrary to the eighties, were associated with two *Fusarium* species, *F. subglutinans* and to a lesser extent *F. graminearum*. Infected kernels were also linked to high rainfall in July, the anthesis period, in the case of *F. graminearum* but also to low rainfall with *F. subglutinans*. The occurrence of secondary damage to kernels also proved to be of importance, especially from insects, mainly borers such as *Ostrinia nubilalis*, and to a lesser extent from birds, two vectors reported in the early eighties (Sutton 1982).

A major finding of this study is the presence of a major *Fusarium* species, *F. subglutinans*, on ear rot infected kernels in association with low rainfall in July. Therefore, under drought conditions found in Ontario, ear rot incidence can still be severe but less toxic, since the moniliformin mycotoxin produced by *F. subglutinans* is less toxic to animals. The *Fusarium graminearum* mycotoxin, deoxynivalenol, is produced under wet conditions in July. These results indicate that breeding for resistance to ear rot aimed at controlling this disease in Ontario must also take into account the potential infection by other *Fusarium* species beside *F. graminearum*.

To establish the reliability of disease resistance of new maize genotypes developed through a disease resistance breeding program, these genotypes have to be exposed to different environmental conditions and evaluated for levels of infection (Chapter III). Here, for the first time, a negative correlation was found between higher levels of fusarium ear rot and grain yield when the infection simulates a slight kernel damage by pests. Direct kernel resistance to gibberella ear rot induced by *F. graminearum* shows a stable resistance for inbred line CO325 under severe infection levels as observed on susceptible genotypes used in the study. Kernel resistance mechanisms could also be more in line with reality as secondary damage to kernels were recorded as components in the predictive

model developed in Chapter II. Kernel resistance mechanisms could be linked to another passive trait, i.e. the ability of kernels to mature more rapidly and act as a physical barrier against pathogen invasion.

The source of genotype by environment interaction was identified by two different approaches. The AMMI model was able to capture only 68% of the interaction across both inoculation methods, compared to 84% for the joint regression model. However, the AMMI model gave additional visual information with the biplot diagram constructed with one IPCA score. The results showed the difference that exists between environments in terms of their interactions on the expression of resistance of genotypes to gibberella ear rot. It shows in particular that environments located in Ottawa, at the Central Experimental Farm, St-Polycarpe, and Cobden have the highest interaction effect for genotype by environment, among all sites.

We should differentiate at this point between the measurements of fusarium ear rot incidence in Chapter II and ear rot ratings in Chapter III, the first being a quantitative measure of infection and the second being a qualitative measure of severity of the infection.

The study in chapter IV investigates the effect of changes in phenotypic expressions, such as leaf area and plant height with two different row spacings and the results of ear rot on the disease spread. The steepness gradient, or the rate at which the disease is spreading in a field, reveals that gibberella ear rot does not disperse quickly from a single inoculation source. It suggests that multi-infection sources are necessary to create a large disease spread and provoke an epidemic.

Modeling ear rot spread from an inoculum source in maize appears to be feasible with the Power Law model approach. This model was able to express the disease spread within a five meter distance from the inoculum source. However, the method used to monitor the time and level of propagule dispersal from the inoculum source proved to be

lacking in accuracy. The trapping method adapted for these studies appeared to collect all kinds of spores, mostly *Alternaria* species and very few *G. zeae* macroconidia and *F. graminearum* ascospores.

5.2 Implications of the present study

The short distance over which ear rot incidence decreased by 50% (d_{50}) substantiate the fact that disease spread is caused by propagules dispersed by rain-splash rather than by air transport. Under ideal environmental conditions, with high July rainfall and the presence of secondary damage on kernels, gibberella ear rot attacks are likely to be caused by more than one strain and sudden changes in weather conditions such as a dryer period might trigger the spread of fusarium ear rot caused by other *Fusarium* species such as *F. subglutinans* and *F. moniliforme*. The dominance among strains and species is too complex and variable to establish. Therefore a maize breeding program should be oriented towards multi-*Fusarium* species and strain resistance and rely on a large gene pool to obtain a sustainable resistance.

Mechanical barriers to pathogen invasion include the cuticular waxes in plants. This provides a water-repellent surface that can prevent fungal spores from penetrating into the plant or allow them to be easily washed off the leaves. Other physical barrier mechanisms particular to maize could be present such as the length and the tightness of the silk channel sheath that protect silks from direct contact with infection sources. Kernel resistance may be linked with pericarp thickness as well as the presence of phytochemicals that may destroy toxins produced by pathogenic fungi.

Changes in the North-American agrosystem tend to favor less disturbance of the soil surface with a narrow range of plant species produced year after year that can push to the limit the adaptive capacity of plant species based on a narrow gene pool (Fig. 6.1). The recent collapse of the winter wheat production in northern U.S.A. due to fusarium head blight epidemics can also be an early warning sign for maize. The adaptation of southern *Fusarium* species to northern climates such as *Fusarium moniliforme* which was non

existent in eastern Canada 15 years ago could be a hazard as well. Newly developed transgenic maize hybrids with *Bacillus thuringensis* genes that are resistant to maize borers can increase the pressure on non-resistant maize hybrids and induce more secondary damage in susceptible maize.

As agriculture systems become more intensified, it is important to develop quantitative resistance mechanisms rather than qualitative ones. These quantitative traits should be oriented towards mechanisms that restrict mycelium propagation such as high moisture or nutrient levels, slowing down the infection process. A rapid dry down of silk and kernels should be beneficial in reducing mycelium growth. In the context of global warming these criteria could be reached in southern regions of the globe. However, a rapid silk channel dry down could reduce pollination efficiency and kernel growth. Silk tissue being 90% water, a protective layer that can prevent desiccation and offer a barrier against hyphae penetration should be a good strategy for developing resistance mechanisms in maize.

5.3 Future work

The first generation model to predict the occurrence of fusarium ear rot should be tested further on independent data and should be tested across a broader range of environments to test its reliability. It could be used as a first step in building a predictive tool to forecast potential fusarium ear rot epidemics mainly when mycotoxin producing *Fusarium graminearum* is active. Studies on *Fusarium* species interactions as a form of biocontrol should be undertaken to measure their effects on toxic fusarium ear rot.

Coupling disease spread models with crop growth models should be developed as a predictive tool and as a way to simulate the severity of fusarium ear rot damage.

Studies on the impact of present cultural practices on the severity of fusarium ear rot attacks on maize in association with weather parameters should be undertaken in the light of changes occurring over the past ten years, such as the interactions between an

increasing number of *Fusarium* species at infection sites. Trends in reduced tillage and higher nitrogen fertilizer applied under different forms should also be considered in this investigation.

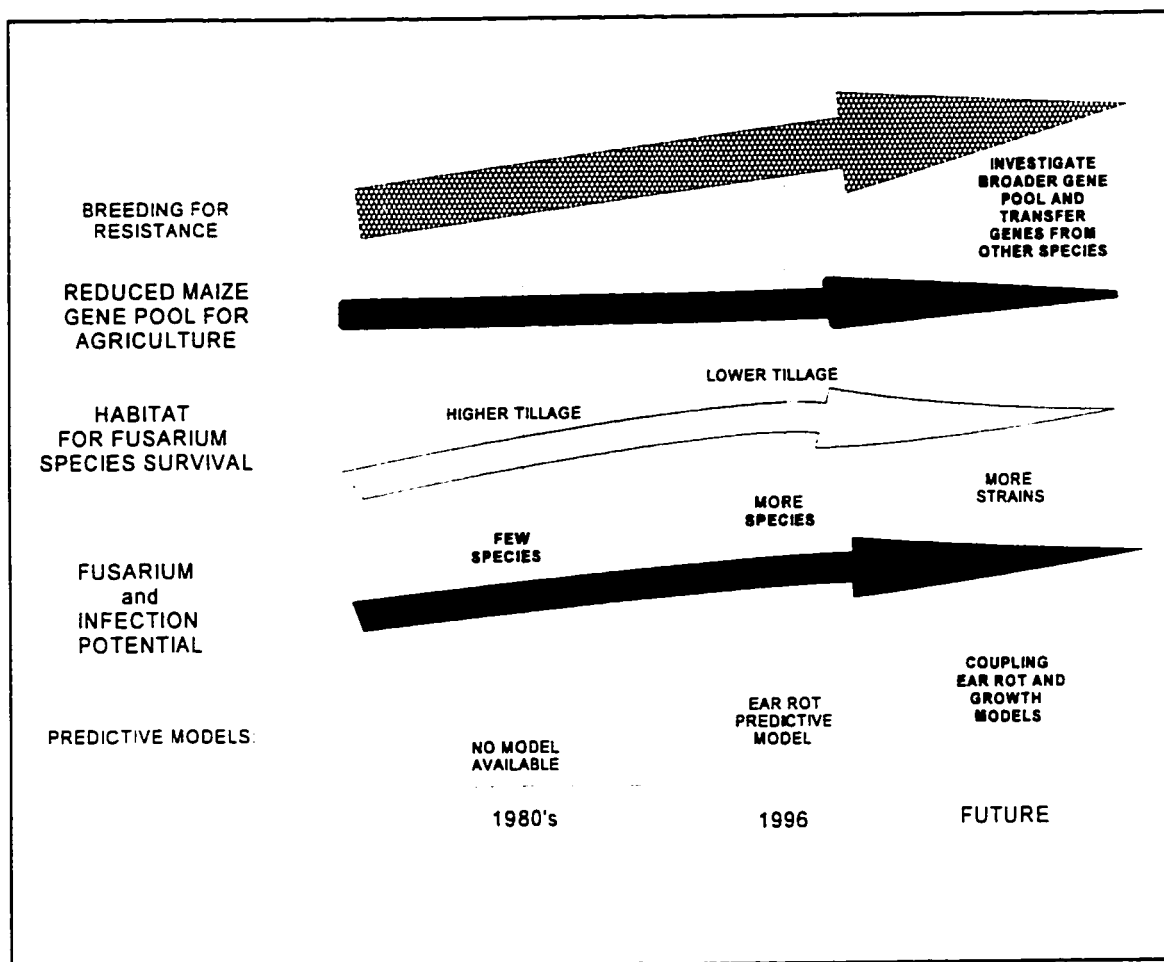
A focus on potential monogenic resistance such as the silk channel resistance should be investigated with a gene transfer approach looking for markers used for the rapid screening of genetic material and incorporating this gene into hybrid maize. Molecular work with the wheat germin gene transfer in maize to increase leaf toughness and possible kernel pericarp thickness should be combined with existent fusarium ear rot resistant inbred lines for additional protection against pests.

On-going breeding for fusarium ear rot resistance studies which are oriented towards polygenic resistance should focus on the medium term to test improved resistance characters for multi-pest resistance to broaden the adaptability of new genotypes across different environments and exposure to other pests such as fungal leaf blights and borer insects.

Fig. 6.1. Diagram of factors that have an impact on the fusarium disease complex in maize, and breeding strategies for resistance, starting from the eighties, now, and in the future.

Considerations are given to a reduced maize gene pool for agriculture as seeds companies tend to rely on fewer breeding parents that have high yield performance, tillage practices that increase infected plant debris on the soil surface, the northern movement of *Fusarium* species with the effect of global warming and the multiplication of *Fusarium* species and strains with the availability of host plants.

Fig. 6.1



CHAPTER VI

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APPENDIX

-----Table 1A

APPENDIX

Table 1B-----

--- ENV=1 TRT=1						-- ENV=1 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3045.661	507.610	12.880	0.0010	Model	7	1410.831	201.547	1.250	0.3764
Error	8	315.218	39.402			Error	8	1287.009	160.876		
Corrected Total	14	3360.879				Corrected Total	15	2697.841			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	264.118	88.039	2.230	0.162	BLOCK	3	915.749	305.250	1.900	0.209
GENO	3	2781.543	927.181	23.530	0.0003	GENO	4	495.082	123.771	0.770	0.5743
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	248.998	82.999	2.110	0.178	BLOCK	3	621.670	207.223	1.290	0.343
GENO	3	2781.543	927.181	23.530	0.0003	GENO	4	495.082	123.771	0.770	0.5743
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.906	17.473	6.277	35.925			0.523	11.451	12.684	110.763		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 2A

APPENDIX

Table 2B-----

--- ENV=1 TRT=2						-- ENV=1 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2650.276	441.713	9.580	0.0073	Model	7	7274.365	1039.195	2.040	0.1327
Error	6	276.730	46.122			Error	12	6111.956	509.330		
Corrected Total	12	2927.006				Corrected Total	19	3386.321			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	12.345	4.115	0.090	0.963	BLOCK	3	2996.587	998.862	1.960	0.174
GENO	3	2637.931	879.310	19.070	0.0018	GENO	4	4277.778	1069.444	2.100	0.1438
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	212.733	70.911	1.540	0.299	BLOCK	3	2996.587	998.862	1.960	0.174
GENO	3	2637.931	879.310	19.070	0.0018	GENO	4	4277.778	1069.444	2.100	0.1438
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.905	19.212	6.791	35.349			0.543	24.853	22.568	90.807		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 3B-----

--- ENV=2 TRT=1						-- ENV=2 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3555.852	592.642	17.700	0.0002	Model	7	3447.703	492.529	5.670	0.0045
Error	9	301.268	33.474			Error	12	1042.217	86.851		
Corrected Total	15	3857.120				Corrected Total	19	4489.920			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	35.982	11.994	0.360	0.785	BLOCK	3	1882.543	627.514	7.230	0.005
GENO	3	3519.870	1173.290	35.050	0.0001	GENO	4	1565.160	391.290	4.510	0.0188
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	55.913	18.638	0.560	0.657	BLOCK	3	1882.543	627.514	7.230	0.005
GENO	3	3519.870	1173.290	35.050	0.0001	GENO	4	1565.160	391.290	4.510	0.0188
R-Square	0.922	20.792	Root MSE	5.786	VAR5 Mean	27.827	R-Square	0.768	9.977	Root MSE	9.319
						VAR5 Mean 93.406					

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 4A

APPENDIX

Table 4B

--- ENV=2 TRT=2						-- ENV=2 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3941.560	656.927	51.970	0.0001	Model	7	6223.809	889.116	1.580	0.2317
Error	9	113.756	12.640			Error	12	6748.760	562.397		
Corrected Total	15	4055.315				Corrected Total	19	2972.569			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	109.702	36.567	2.890	0.095	BLOCK	3	1025.567	341.856	0.610	0.623
GENO	3	3831.857	1277.286	101.050	0.0001	GENO	4	5198.242	1299.560	2.310	0.1173
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	109.702	36.567	2.890	0.095	BLOCK	3	1025.567	341.856	0.610	0.623
GENO	3	3831.857	1277.286	101.050	0.0001	GENO	4	5198.242	1299.560	2.310	0.1173
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.972	14.590	3.555	24.368			0.480	27.128	23.715	87.419		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 5A

APPENDIX

Table 5B-----

--- ENV=3 TRT=1						-- ENV=3 TRT=1									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	6	2541.537	423.589	2.150	0.1560	Model	6	2448.830	408.138	2.260	0.1724				
Error	8	1575.001	196.875			Error	6	1084.432	180.739						
Corrected Total	14	4116.538				Corrected Total	12	3533.262							
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	688.447	229.482	1.170	0.381	BLOCK	3	255.418	85.139	0.470	0.714				
GENO	3	1853.090	617.697	3.140	0.0871	GENO	3	2193.412	731.137	4.050	0.0686				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	827.888	275.963	1.400	0.311	BLOCK	3	598.432	199.477	1.100	0.418				
GENO	3	1853.090	617.697	3.140	0.0871	GENO	3	2193.412	731.137	4.050	0.0686				
R-Square	0.617	C.V.	66.364	Root MSE	14.031	VAR5 Mean	21.143	R-Square	0.693	C.V.	32.056	Root MSE	13.444	VAR5 Mean	41.939

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 6A

APPENDIX

Table 6B-----

--- ENV=3 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	633.705	105.618	13.120	0.0005
Error	9	72.435	8.048		
Corrected Total	15	706.140			
--- ENV=3 TRT=2					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	18.403	6.134	0.760	0.543
GENO	3	615.302	205.101	25.480	0.0001
--- ENV=3 TRT=2					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	18.403	6.134	0.760	0.543
GENO	3	615.302	205.101	25.480	0.0001
R-Square	0.897	23.220	Root MSE	2.837	VAR5 Mean
					12.218
--- ENV=3 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1220.858	203.476	7.810	0.0122
Error	6	156.276	26.046		
Corrected Total	12	1377.134			
--- ENV=3 TRT=2					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	211.742	70.581	2.710	0.138
GENO	3	1009.116	336.372	12.910	0.0050
--- ENV=3 TRT=2					
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	113.175	37.725	1.450	0.319
GENO	3	1009.116	336.372	12.910	0.0050
R-Square	0.887	14.778	Root MSE	5.104	VAR5 Mean
					34.535

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 7A

APPENDIX

Table 7B-----

--- ENV=4 TRT=1						-- ENV=4 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1229.015	204.836	5.150	0.0462	Model	7	890.215	127.174	1.550	0.2399
Error	5	198.702	39.740			Error	12	982.828	81.902		
Corrected Total	11	1427.717				Corrected Total	19	873.043			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	167.039	55.680	1.400	0.345	BLOCK	3	232.268	77.423	0.950	0.449
GENO	3	1061.976	353.992	8.910	0.0189	GENO	4	657.947	164.487	2.010	0.1573
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	102.203	34.068	0.860	0.520	BLOCK	3	232.268	77.423	0.950	0.449
GENO	3	1061.976	353.992	8.910	0.0189	GENO	4	657.947	164.487	2.010	0.1573
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.861	17.850	6.304	35.317			0.475	8.827	9.050	102.522		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 8A

APPENDIX

Table 8B-----

--- ENV=4 TRT=2						-- ENV=4 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1883.704	313.951	5.600	0.0392	Model	7	2800.876	400.125	5.530	0.0050
Error	5	280.475	56.095			Error	12	867.942	72.328		
Corrected Total	11	2164.180				Corrected Total	19	3668.818			
Source						Source					
DF	Type I SS	Mean Square	F Value	Pr > F		DF	Type I SS	Mean Square	F Value	Pr > F	
3	254.148	84.716	1.510	0.320		3	498.551	166.184	2.300	0.130	
3	1629.557	543.186	9.680	0.0159		4	2302.326	575.581	7.960	0.0023	
Source						Source					
DF	Type III SS	Mean Square	F Value	Pr > F		DF	Type III SS	Mean Square	F Value	Pr > F	
3	143.256	47.752	0.850	0.523		3	498.551	166.184	2.300	0.130	
3	1629.557	543.186	9.680	0.0159		4	2302.326	575.581	7.960	0.0023	
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.870	27.769	7.490	26.972			0.763	10.714	8.505	79.378		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 9A

APPENDIX

Table 9B-----

--- ENV=5 TRT=1						-- ENV=5 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2263.328	377.221	58.240	0.0001	Model	7	2820.034	402.862	2.120	0.1360
Error	9	58.290	6.477			Error	10	1901.404	190.140		
Corrected Total	15	2321.618				Corrected Total	17	4721.438			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	6.602	2.201	0.340	0.797	BLOCK	3	1265.678	421.893	2.220	0.149
GENO	3	2256.726	752.242	116.150	0.0001	GENO	4	1554.357	388.589	2.040	0.1638
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	6.602	2.201	0.340	0.797	BLOCK	3	876.410	292.137	1.540	0.265
GENO	3	2256.726	752.242	116.150	0.0001	GENO	4	1554.357	388.589	2.040	0.1638
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.975	8.934	2.545	28.486			0.597	15.844	13.789	87.031		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 10A

APPENDIX

Table 10B-----

--- ENV=5 TRT=2						-- ENV=5 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	364.721	60.787	2.550	0.1396	Model	7	1857.297	265.328	2.290	0.0986
Error	6	142.941	23.824			Error	12	1387.417	115.618		
Corrected Total	12	507.662				Corrected Total	19	3244.715			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	72.867	24.289	1.020	0.448	BLOCK	3	305.540	101.847	0.880	0.478
GENO	3	291.854	97.285	4.080	0.0674	GENO	4	1551.757	387.939	3.360	0.0461
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	30.591	10.197	0.430	0.740	BLOCK	3	305.540	101.847	0.880	0.478
GENO	3	291.854	97.285	4.080	0.0674	GENO	4	1551.757	387.939	3.360	0.0461
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.718	19.318	4.881	25.267			0.572	14.051	10.753	76.526		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 11A

APPENDIX

Table 11B-----

--- ENV=6 TRT=1							-- ENV=6 TRT=1						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F		Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	6	1409.111	234.852	4.640	0.0201		Model	7	2621.736	374.534	2.440	0.0836	
Error	9	455.205	50.578				Error	12	1841.807	153.484			
Corrected Total	15	1864.316					Corrected Total	19	4463.543				
Source	DF	Type I SS	Mean Square	F Value	Pr > F		Source	DF	Type I SS	Mean Square	F Value	Pr > F	
BLOCK	3	67.865	22.622	0.450	0.725		BLOCK	3	571.605	190.535	1.240	0.338	
GENO	3	1341.246	447.082	8.840	0.0048		GENO	4	2050.132	512.533	3.340	0.0467	
Source	DF	Type III SS	Mean Square	F Value	Pr > F		Source	DF	Type III SS	Mean Square	F Value	Pr > F	
BLOCK	3	67.865	22.622	0.450	0.725		BLOCK	3	571.605	190.535	1.240	0.338	
GENO	3	1341.246	447.082	8.840	0.0048		GENO	4	2050.132	512.533	3.340	0.0467	
R-Square	C.V.	Root MSE	VAR5 Mean				R-Square	C.V.	Root MSE	VAR5 Mean			
0.756	29.353	7.112	24.229				0.587	16.854	12.389	73.509			

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 12B-----

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 13A

APPENDIX

Table 13B-----

--- ENV=7 TRT=1						-- ENV=7 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1218.544	203.091	4.850	0.0288	Model	7	897.019	128.146	1.440	0.2838
Error	7	293.352	41.907			Error	11	981.522	89.229		
Corrected Total	13	1511.896				Corrected Total	18	878.541			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	63.962	21.321	0.510	0.689	BLOCK	3	523.484	174.495	1.960	0.179
GENO	3	1154.582	384.861	9.180	0.0080	GENO	4	373.535	93.384	1.050	0.4270
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.926	0.309	0.010	0.999	BLOCK	3	577.144	192.381	2.160	0.151
GENO	3	1154.582	384.861	9.180	0.0080	GENO	4	373.535	93.384	1.050	0.4270
R-Square	C.V.	Root MSE	VAR5 Mean								
0.806	17.254	6.474	37.519	0.478	10.470	Root MSE	C.V.	9.446	VAR5 Mean	90.225	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 14A

APPENDIX

Table 14B-----

--- ENV=7 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	6	1389.918	231.653	13.300	0.0005				
Error	9	156.729	17.414						
Corrected Total	15	1546.647							
-- ENV=7 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	7	642.551	91.793	0.340	0.9187				
Error	12	217.801	268.150						
Corrected Total	19	860.352							
Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	120.991	40.330	0.150	0.927				
GENO	4	521.560	130.390	0.490	0.7458				
Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	120.991	40.330	0.150	0.927				
GENO	4	521.560	130.390	0.490	0.7458				
R-Square	0.899	C.V.	20.952	Root MSE	16.375	VAR5 Mean	78.157		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 15A

APPENDIX

Table 15B

--- ENV=8 TRT=1						-- ENV=8 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1061.222	176.870	12.070	0.0022	Model	7	846.695	120.956	2.560	0.0794
Error	7	102.562	14.652			Error	11	520.174	47.289		
Corrected Total	13	1163.783				Corrected Total	18	366.869			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	104.364	34.788	2.370	0.156	BLOCK	3	546.959	182.320	3.860	0.042
GENO	3	956.857	318.952	21.770	0.0006	GENO	4	299.735	74.934	1.580	0.2465
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	64.243	21.414	1.460	0.305	BLOCK	3	535.773	178.591	3.780	0.044
GENO	3	956.857	318.952	21.770	0.0006	GENO	4	299.735	74.934	1.580	0.2465
R-Square	0.912	Root MSE				R-Square	0.619	Root MSE			
		12.059	3.828				7.919	6.877		VAR5 Mean	
										86.843	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 16A

APPENDIX

Table 16B-----

--- ENV=8 TRT=2						-- ENV=8 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	946.535	157.756	14.080	0.0014	Model	7	2196.926	313.847	5.070	0.0071
Error	7	78.446	11.207			Error	12	743.138	61.928		
Corrected Total	13	1024.981				Corrected Total	19	2940.064			
Source						Source					
BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F
GENO	3	93.499	31.166	2.780	0.120	GENO	3	486.615	162.205	2.620	0.099
	3	853.036	284.345	25.370	0.0004		4	1710.311	427.578	6.900	0.0040
Source						Source					
BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F
GENO	3	38.186	12.729	1.140	0.398	GENO	3	486.615	162.205	2.620	0.099
	3	853.036	284.345	25.370	0.0004		4	1710.311	427.578	6.900	0.0040
R-Square	0.923	C.V.	11.222	Root MSE	3.348	R-Square	0.747	C.V.	9.186	Root MSE	7.869
										VAR5 Mean	85.669

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 17A

APPENDIX

Table 17B-----

--- ENV=9 TRT=1						-- ENV=9 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	1178.885	196.481	3.250	0.0551	Model	7	8563.707	1223.387	4.170	0.0149
Error	9	543.672	60.408			Error	12	3521.758	293.480		
Corrected Total	15	1722.557				Corrected Total	19	2085.465			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	46.603	15.534	0.260	0.854	BLOCK	3	201.371	67.124	0.230	0.875
GENO	3	1132.282	377.427	6.250	0.0140	GENO	4	8362.335	2090.584	7.120	0.0035
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	46.603	15.534	0.260	0.854	BLOCK	3	201.371	67.124	0.230	0.875
GENO	3	1132.282	377.427	6.250	0.0140	GENO	4	8362.335	2090.584	7.120	0.0035
R-Square	0.684					R-Square	0.709				
C.V.	29.294					C.V.	21.825				
Root MSE	7.772					Root MSE	17.131				
VAR5 Mean	26.532					VAR5 Mean	78.495				

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 18A

APPENDIX

Table 18B-----

--- ENV=9 TRT=2						-- ENV=9 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3290.917	548.486	16.340	0.0002	Model	7	2551.089	364.441	1.060	0.4417
Error	9	302.168	33.574			Error	12	4119.131	343.261		
Corrected Total	15	3593.085				Corrected Total	19	6670.219			
Source						Source					
DF	Type I SS	Mean Square	F Value	Pr > F		DF	Type I SS	Mean Square	F Value	Pr > F	
BLOCK	3	72.105	24.035	0.720	0.567	BLOCK	3	981.474	327.158	0.950	0.446
GENO	3	3218.812	1072.937	31.960	0.0001	GENO	4	1569.614	392.404	1.140	0.3827
Source						Source					
DF	Type III SS	Mean Square	F Value	Pr > F		DF	Type III SS	Mean Square	F Value	Pr > F	
BLOCK	3	72.105	24.035	0.720	0.567	BLOCK	3	981.474	327.158	0.950	0.446
GENO	3	3218.812	1072.937	31.960	0.0001	GENO	4	1569.614	392.404	1.140	0.3827
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.916	21.091	5.794	27.473			0.382	21.393	18.527	86.607		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 19B-----

--- ENV=10 TRT=1						- ENV=10 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	923.118	153.853	14.020	0.0116	Model	7	1406.803	200.972	1.300	0.3504
Error	4	43.903	10.976			Error	9	1395.667	155.074		
Corrected Total	10	967.020				Corrected Total	16	2802.470			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	194.656	64.885	5.910	0.060	BLOCK	3	200.437	66.812	0.430	0.736
GENO	3	728.461	242.820	22.120	0.0059	GENO	4	1206.366	301.591	1.940	0.1871
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	12.216	4.072	0.370	0.779	BLOCK	3	189.908	63.303	0.410	0.751
GENO	3	728.461	242.820	22.120	0.0059	GENO	4	1206.366	301.591	1.940	0.1871
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.955	13.180	3.313	25.135			0.502	13.027	12.453	95.592		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 21A

APPENDIX

Table 21B

--- ENV=11 TRT=1						-- ENV=11 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2282.957	380.493	13.210	0.0031	Model	7	2180.391	311.484	1.270	0.3395
Error	6	172.772	28.795			Error	12	2933.179	244.432		
Corrected Total	12	2455.729				Corrected Total	19	5113.570			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	434.095	144.698	5.030	0.045	BLOCK	3	607.946	202.649	0.830	0.503
GENO	3	1848.862	616.287	21.400	0.0013	GENO	4	1572.445	393.111	1.610	0.2355
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	98.117	32.706	1.140	0.407	BLOCK	3	607.946	202.649	0.830	0.503
GENO	3	1848.862	616.287	21.400	0.0013	GENO	4	1572.445	393.111	1.610	0.2355
R-Square	0.930					R-Square	0.426				
		C.V.	16.406					C.V.	14.854		
		Root MSE	5.366					Root MSE	15.634		
		VAR5 Mean	32.708					VAR5 Mean	105.250		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 22A

APPENDIX

Table 22B

--- ENV=11 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	6	1207.614	201.269	23.490	0.0016				
Error	5	42.848	8.570						
Corrected Total	11	1250.463							
--- ENV=11 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	7	2589.861	369.980	2.450	0.0829				
Error	12	1813.941	151.162						
Corrected Total	19	4403.802							
--- ENV=11 TRT=2									
Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	357.574	119.191	0.790	0.523				
GENO	4	2232.287	558.072	3.690	0.0350				
--- ENV=11 TRT=2									
Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	357.574	119.191	0.790	0.523				
GENO	4	2232.287	558.072	3.690	0.0350				
--- ENV=11 TRT=2									
R-Square	C.V.	Root MSE	VAR5 Mean						
0.966	8.171	2.927	35.825						
--- ENV=11 TRT=2									
R-Square	C.V.	Root MSE	VAR5 Mean						
0.588	12.267	12.295	100.230						

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 23A

APPENDIX

Table 23B

--- ENV=12 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	912.965	152.161	0.600	0.7231
Error	5	1261.527	252.305		
Corrected Total	11	2174.491			
-- ENV=12 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	6939.440	991.349	3.160	0.0432
Error	11	3446.832	313.348		
Corrected Total	18	386.272			
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	3742.855	1247.618	3.980	0.038
GENO	4	3196.584	799.146	2.550	0.0987
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	3569.080	1189.693	3.800	0.043
GENO	4	3196.584	799.146	2.550	0.0987
R-Square	C.V.	Root MSE	VAR5 Mean		
0.420	54.302	15.884	29.252	0.668	17.702
					110.108

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 24A

APPENDIX

Table 24B-----

--- ENV=12 TRT=2						-- ENV=12 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	2135.294	355.882	12.300	0.0073	Model	7	4343.791	620.542	1.610	0.2299
Error	5	144.685	28.937			Error	11	4234.278	384.934		
Corrected Total	11	2279.979				Corrected Total	18	8578.069			
Source						Source					
Block	DF	Type I SS	Mean Square	F Value	Pr > F	Block	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	379.758	126.586	4.370	0.073	BLOCK	3	1844.486	614.829	1.600	0.246
GENO	3	1755.536	585.179	20.220	0.0032	GENO	4	2499.305	624.826	1.620	0.2371
Source						Source					
Block	DF	Type III SS	Mean Square	F Value	Pr > F	Block	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	237.762	79.254	2.740	0.153	BLOCK	3	1533.107	511.036	1.330	0.315
GENO	3	1755.536	585.179	20.220	0.0032	GENO	4	2499.305	624.826	1.620	0.2371
R-Square	0.937	C.V.	Root MSE	VAR5 Mean	30.758	R-Square	0.506	Root MSE	VAR5 Mean	100.982	
		17.489	5.379				19.429	19.620			

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 25A

APPENDIX

Table 25B-----

--- ENV=13 TRT=1						-- ENV=13 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	1416.256	708.128			Model	7	7040.043	1005.720	1.600	0.2328
Error	0					Error	11	6907.489	627.954		
Corrected Total	2	1416.256				Corrected Total	18	3947.532			
Type I SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	2	1416.256	708.128			BLOCK	3	2082.852	694.284	1.110	0.388
GENO	0	0.000				GENO	4	4957.191	1239.298	1.970	0.1683
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	1	1406.090	1406.090			BLOCK	3	2106.654	702.218	1.120	0.384
GENO	0	0.000				GENO	4	4957.191	1239.298	1.970	0.1683
R-Square	C.V.	Root MSE	VAR5 Mean								
1.000	0.000	0.000	48.133	0.505	23.008	R-Square	C.V.	Root MSE	VAR5 Mean		
										108.912	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 26A

APPENDIX

Table 26B-----

--- ENV=13 TRT=2						-- ENV=13 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	101.786	50.893			Model	7	3892.702	556.100	0.500	0.8182
Error	0					Error	10	1224.586	1122.459		
Corrected Total	2	101.786				Corrected Total	17	5117.288			
Source						Source					
BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F
GENO	1	1.392	1.392			GENO	3	1734.422	578.141	0.520	0.681
	1	100.394	100.394				4	2158.280	539.570	0.480	0.7497
Source						Source					
BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F
GENO	1	36.380	36.380			GENO	3	1723.728	574.576	0.510	0.683
	1	100.394	100.394				4	2158.280	539.570	0.480	0.7497
R-Square	1.000	C.V.	0.000	Root MSE	VAR5 Mean	R-Square	0.258	C.V.	32.020	Root MSE	VAR5 Mean
					20.717				33.503		104.631

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 27A

APPENDIX

Table 27B-----

--- ENV=14 TRT=1						-- ENV=14 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	214.492	42.898	0.210	0.9463	Model	7	4902.128	700.304	1.960	0.1536
Error	5	1043.788	208.758			Error	11	3935.753	357.796		
Corrected Total	10	1258.280				Corrected Total	18	8837.881			
Source						Source					
BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type I SS	Mean Square	F Value	Pr > F
GENO	2	206.661	68.887	0.330	0.805	GENO	3	1779.605	593.202	1.660	0.233
		7.831	3.916	0.020	0.9815		4	3122.524	780.631	2.180	0.1382
Source						Source					
BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F	BLOCK	DF	Type III SS	Mean Square	F Value	Pr > F
GENO	2	197.606	65.869	0.320	0.814	GENO	3	1390.732	463.577	1.300	0.325
		7.831	3.916	0.020	0.9815		4	3122.524	780.631	2.180	0.1382
R-Square	0.170	43.298				R-Square	0.555	25.526			
C.V.			Root MSE	14.448	33.370	C.V.			Root MSE	18.915	74.103
VAR5 Mean						VAR5 Mean					

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 28A

APPENDIX

Table 28B-----

--- ENV=14 TRT=2						-- ENV=14 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	241.217	60.304			Model	7	7229.537	1032.791	2.730	0.1213
Error	0					Error	6	2272.929	378.822		
Corrected Total	4	241.217				Corrected Total	13	9502.465			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	221.246	73.749			BLOCK	3	5113.953	1704.651	4.500	0.056
GENO	1	19.971	19.971			GENO	4	2115.583	528.896	1.400	0.3399
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	216.330	72.110			BLOCK	3	4947.520	1649.173	4.350	0.060
GENO	1	19.971	19.971			GENO	4	2115.583	528.896	1.400	0.3399
R-Square						R-Square					
	1.000										

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 29A

APPENDIX

Table 29B

--- ENV=15 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2037.948	509.487	33.080	0.0296
Error	2	30.799	15.399		
Corrected Total	6	2068.746			
--- ENV=15 TRT=1					
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	2	518.464	259.232	16.830	0.056
GENO	2	1519.483	759.742	49.340	0.0199
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	2	15.932	7.966	0.520	0.659
GENO	2	1519.483	759.742	49.340	0.0199
R-Square	0.985	C.V.	10.507	Root MSE	3.924
				VAR5 Mean	37.349
--- ENV=15 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	7	2218.151	316.879	0.480	0.8294
Error	11	7241.458	658.314		
Corrected Total	18	9459.609			
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	745.720	248.573	0.380	0.771
GENO	4	1472.431	368.108	0.560	0.6971
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	475.353	158.451	0.240	0.866
GENO	4	1472.431	368.108	0.560	0.6971
R-Square	0.234	C.V.	26.537	Root MSE	25.658
				VAR5 Mean	96.685

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 30A

APPENDIX

Table 30B-----

--- ENV=15 TRT=2						-- ENV=15 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	4	419.903	104.976	3.850	0.3628	Model	7	11454.210	1636.316	1.030	0.4711				
Error	1	27.248	27.248			Error	9	14276.190	1586.243						
Corrected Total	5	447.151				Corrected Total	16	25730.400							
--- ENV=15 TRT=2						-- ENV=15 TRT=2									
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	2	146.125	73.063	2.680	0.396	BLOCK	3	5949.901	1983.300	1.250	0.348				
GENO	2	273.777	136.889	5.020	0.3009	GENO	4	5504.313	1376.078	0.870	0.5192				
--- ENV=15 TRT=2						-- ENV=15 TRT=2									
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	2	122.296	61.148	2.240	0.427	BLOCK	3	5696.293	1898.764	1.200	0.365				
GENO	2	273.777	136.889	5.020	0.3009	GENO	4	5504.313	1376.078	0.870	0.5192				
R-Square	0.939	C.V.	15.416	Root MSE	5.220	VAR5 Mean	33.860	R-Square	0.445	C.V.	39.469	Root MSE	39.828	VAR5 Mean	100.909

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 31A

APPENDIX

Table 31B-----

--- ENV=16 TRT=1						--- ENV=16 TRT=1									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	6	2683.415	447.236	0.810	0.6257	Model	7	5329.375	761.339	1.970	0.1512				
Error	3	1666.039	555.346			Error	11	4249.602	386.327						
Corrected Total	9	4349.454				Corrected Total	18	9578.977							
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	1337.792	445.931	0.800	0.569	BLOCK	3	2199.096	733.032	1.900	0.189				
GENO	3	1345.623	448.541	0.810	0.5676	GENO	4	3130.280	782.570	2.030	0.1601				
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	488.582	162.861	0.290	0.830	BLOCK	3	1872.375	624.125	1.620	0.242				
GENO	3	1345.623	448.541	0.810	0.5676	GENO	4	3130.280	782.570	2.030	0.1601				
R-Square	0.617	C.V.	63.508	Root MSE	23.566	VAR5 Mean	37.107	R-Square	0.556	C.V.	17.295	Root MSE	19.655	VAR5 Mean	113.645

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 32A

APPENDIX

Table 32B

--- ENV=16 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	6	699.696	116.616	1.220	0.4714				
Error	3	286.780	95.593						
Corrected Total	9	986.476							
--- ENV=16 TRT=2									
Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	339.474	113.158	1.180	0.447				
GENO	3	360.223	120.074	1.260	0.4279				
Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	113.166	37.722	0.390	0.767				
GENO	3	360.223	120.074	1.260	0.4279				
R-Square	0.709	22.913	C.V.	Root MSE	9.777	VAR5 Mean			
						42.670			
--- ENV=16 TRT=2									
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F				
Model	7	9485.550	1355.079	1.610	0.2244				
Error	12	120.073	843.339						
Corrected Total	19	9605.623							
Source	DF	Type I SS	Mean Square	F Value	Pr > F				
BLOCK	3	6067.434	2022.478	2.400	0.119				
GENO	4	3418.116	854.529	1.010	0.4388				
Source	DF	Type III SS	Mean Square	F Value	Pr > F				
BLOCK	3	6067.434	2022.478	2.400	0.119				
GENO	4	3418.116	854.529	1.010	0.4388				
R-Square	0.484	28.051	C.V.	Root MSE	29.040	VAR5 Mean			
						103.526			

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 33A

APPENDIX

Table 33B-----

			--- ENV=17 TRT=1						-- ENV=17 TRT=1		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	2940.766	735.192			Model	7	6858.216	979.745	0.760	0.6287
Error	0					Error	12	5430.503	1285.875		
Corrected Total	4	2940.766				Corrected Total	19	2288.719			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2848.286	949.429			BLOCK	3	2709.256	903.085	0.700	0.569
GENO	1	92.480	92.480			GENO	4	4148.960	1037.240	0.810	0.5442
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	2	1942.822	971.411			BLOCK	3	2709.256	903.085	0.700	0.569
GENO	1	92.480	92.480			GENO	4	4148.960	1037.240	0.810	0.5442
R-Square	C.V.	Root MSE	VAR5 Mean								
1.000	0.000	0.000	47.564			R-Square	0.308	Root MSE		VAR5 Mean	
							35.727	35.859		100.370	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 34A

APPENDIX

Table 34B-----

--- ENV=17 TRT=2						-- ENV=17 TRT=2					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	8598.881	1433.147	1.110	0.4803	Model	7	7597.458	1085.351	0.880	0.5541
Error	4	5148.195	1287.049			Error	11	3631.190	1239.199		
Corrected Total	10	13747.076				Corrected Total	18	1228.649			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2531.126	843.709	0.660	0.621	BLOCK	3	3980.360	1326.787	1.070	0.401
GENO	3	6067.755	2022.585	1.570	0.3281	GENO	4	3617.098	904.275	0.730	0.5901
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	2611.020	870.340	0.680	0.611	BLOCK	3	3992.064	1330.688	1.070	0.400
GENO	3	6067.755	2022.585	1.570	0.3281	GENO	4	3617.098	904.275	0.730	0.5901
R-Square	C.V.	Root MSE	VAR5 Mean			R-Square	C.V.	Root MSE	VAR5 Mean		
0.626	67.235	35.875	53.358			0.358	41.518	35.202	84.787		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 35A

APPENDIX

Table 35B

			- ENV=1 TRT=1 -						- ENV=1 TRT=1 -		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10.829	1.805	9.980	0.0024	Model	7	3.091	0.442	2.940	0.0672
Error	8	1.447	0.181			Error	9	1.350	0.150		
Corrected Total	14	12.276				Corrected Total	16	4.441			
			- ENV=1 TRT=1 -						- ENV=1 TRT=1 -		
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.906	0.302	1.670	0.250	BLOCK	3	0.516	0.172	1.150	0.382
GENO	3	9.923	3.308	18.280	0.0006	GENO	4	2.576	0.644	4.290	0.0324
			- ENV=1 TRT=1 -						- ENV=1 TRT=1 -		
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.424	0.141	0.780	0.537	BLOCK	3	0.495	0.165	1.100	0.398
GENO	3	9.923	3.308	18.280	0.0006	GENO	4	2.576	0.644	4.290	0.0324
			- ENV=1 TRT=1 -						- ENV=1 TRT=1 -		
R-Square	C.V.	Root MSE		RAT Mean		R-Square	C.V.	Root MSE		RAT Mean	
0.882	22.867	0.425		1.860		0.696	23.348	0.387		1.659	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 36A

APPENDIX

Table 36B-----

-- ENV=1 TRT=2						- ENV=1 TRT=2 --					
Source	DF	Squares	Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	20.277	3.380	12.630	0.0011	Model	7	9.259	1.323	39.390	0.0001
Error	8	2.140	0.268			Error	12	0.403	0.034		
Corrected Total	14	22.417				Corrected Total	19	9.662			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.407	0.802	3.000	0.095	BLOCK	3	0.282	0.094	2.800	0.085
GENO	3	17.870	5.957	22.270	0.0003	GENO	4	8.977	2.244	66.830	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	2.447	0.816	3.050	0.092	BLOCK	3	0.282	0.094	2.800	0.085
GENO	3	17.870	5.957	22.270	0.0003	GENO	4	8.977	2.244	66.830	0.0001
R-Square	C.V.	Root MSE		RAT Mean		R-Square	C.V.	Root MSE		RAT Mean	
0.905	11.459	0.517		4.513		0.958	5.048	0.183		3.630	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 37A

APPENDIX

Table 37B

I-- ENV=2 TRT=1						- ENV=2 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	10.284	2.057	8.200	0.0117	Model	7	20.341	2.906	7.310	0.0015
Error	6	1.505	0.251			Error	12	4.769	0.397		
Corrected Total	11	11.789				Corrected Total	19	25.110			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	2	0.062	0.031	0.120	0.887	BLOCK	3	2.594	0.865	2.180	0.144
GENO	3	10.223	3.408	13.580	0.0044	GENO	4	17.747	4.437	11.160	0.0005
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	2	0.062	0.031	0.120	0.887	BLOCK	3	2.594	0.865	2.180	0.144
GENO	3	10.223	3.408	13.580	0.0044	GENO	4	17.747	4.437	11.160	0.0005
R-Square	0.872					R-Square					
C.V.	20.796					C.V.	26.212				
Root MSE		0.501				Root MSE		0.630			
RAT Mean				2.408		RAT Mean				2.405	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 38A

APPENDIX

Table 38B-----

-- ENV=2 TRT=2						- ENV=2 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	5	7.010	1.402	8.760	0.0100	Model	7	10.878	1.554	9.180	0.0005
Error	6	0.960	0.160			Error	12	2.032	0.169		
Corrected Total	11	7.970				Corrected Total	19	12.910			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	2	0.180	0.090	0.560	0.597	BLOCK	3	0.386	0.129	0.760	0.538
GENO	3	6.830	2.277	14.230	0.0039	GENO	4	10.492	2.623	15.490	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	2	0.180	0.090	0.560	0.597	BLOCK	3	0.386	0.129	0.760	0.538
GENO	3	6.830	2.277	14.230	0.0039	GENO	4	10.492	2.623	15.490	0.0001
R-Square	0.880	Root MSE	0.400	RAT Mean	4.350	R-Square	0.843	Root MSE	0.412	RAT Mean	3.605

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 39A

APPENDIX

Table 39B-----

-- ENV=3 TRT=1						- ENV=3 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	33.320	5.553	21.380	0.0001	Model	4	4.388	1.097		
Error	9	2.338	0.260			Error	0				
Corrected Total	15	35.658				Corrected Total	4	4.388			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.493	0.164	0.630	0.613	BLOCK	0	0.000			
GENO	3	32.828	10.943	42.130	0.0001	GENO	4	4.388	1.097		
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.493	0.164	0.630	0.613	BLOCK	0	0.000			
GENO	3	32.828	10.943	42.130	0.0001	GENO	4	4.388	1.097		
R-Square	0.934	Root MSE	0.510	RAT Mean	3.213	R-Square	1.000	Root MSE	0.000	RAT Mean	2.980

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 40A

APPENDIX

Table 40B-----

-- ENV=3 TRT=2 --						- ENV=3 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	7.155	1.193	4.920	0.0169	Model	4	2.828	0.707		
Error	9	2.183	0.243			Error	0				
Corrected Total	15	9.338				Corrected Total	4	2.828			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.173	0.058	0.240	0.868	BLOCK	0	0.000			
GENO	3	6.983	2.328	9.600	0.0036	GENO	4	2.828	0.707		
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.173	0.058	0.240	0.868	BLOCK	0	0.000			
GENO	3	6.983	2.328	9.600	0.0036	GENO	4	2.828	0.707		
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.766	8.735	0.492	5.638			1.000	0.000	0.000	4.180		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 41A

APPENDIX

Table 41B-----

-- ENV=4 TRT=1						-- ENV=4 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	13.914	2.319	21.680	0.0002	Model	7	11.173	1.596	7.050	0.0018
Error	8	0.856	0.107			Error	12	2.715	0.226		
Corrected Total	14	14.769				Corrected Total	19	13.888			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.505	0.835	7.810	0.009	BLOCK	3	1.900	0.633	2.800	0.085
GENO	3	11.409	3.803	35.560	0.0001	GENO	4	9.273	2.318	10.250	0.0008
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	2.946	0.982	9.180	0.006	BLOCK	3	1.900	0.633	2.800	0.085
GENO	3	11.409	3.803	35.560	0.0001	GENO	4	9.273	2.318	10.250	0.0008
R-Square	0.942					R-Square					
	12.610					C.V.	19.494				
						Root MSE	0.476				
										RAT Mean	2.440

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 42A

APPENDIX

Table 42B-----

-- ENV=4 TRT=2						- ENV=4 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3.834	0.639	2.670	0.1000	Model	7	2.847	0.407	4.750	0.0136
Error	8	1.916	0.239			Error	10	0.856	0.086		
Corrected Total	14	5.749				Corrected Total	17	3.703			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.534	0.178	0.740	0.555	BLOCK	3	1.384	0.461	5.390	0.018
GENO	3	3.299	1.100	4.590	0.0376	GENO	4	1.463	0.366	4.270	0.0285
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.529	0.176	0.740	0.559	BLOCK	3	1.026	0.342	3.990	0.042
GENO	3	3.299	1.100	4.590	0.0376	GENO	4	1.463	0.366	4.270	0.0285
Root MSE						Root MSE					
R-Square	0.667	15.751	0.489	RAT Mean 3.107		R-Square	0.769	9.033	RAT Mean 3.239		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 43A

APPENDIX

Table 43B-----

-- ENV=5 TRT=1						- ENV=5 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	16.619	2.770	12.780	0.0010	Model	7	8.195	1.171	5.800	0.0041
Error	8	1.734	0.217			Error	12	2.423	0.202		
Corrected Total	14	18.353				Corrected Total	19	10.618			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.251	0.084	0.390	0.766	BLOCK	3	0.310	0.103	0.510	0.682
GENO	3	16.369	5.456	25.170	0.0002	GENO	4	7.885	1.971	9.760	0.0009
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.060	0.020	0.090	0.962	BLOCK	3	0.310	0.103	0.510	0.682
GENO	3	16.369	5.456	25.170	0.0002	GENO	4	7.885	1.971	9.760	0.0009
R-Square	0.906					R-Square	0.772				
	22.527					C.V	23.343				
		0.466				Root MSE				RAT Mean	
										1.925	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 44A

APPENDIX

Table 44B-----

-- ENV=5 TRT=2 --							- ENV=5 TRT=2 --						
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F		Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	
Model	6	18.055	3.009	20.480	0.0001		Model	7	10.794	1.542	2.790	0.0570	
Error	9	1.323	0.147				Error	12	6.632	0.553			
Corrected Total	15	19.378					Corrected Total	19	17.426				
Source	DF	Type I SS	Mean Square	F Value	Pr > F		Source	DF	Type I SS	Mean Square	F Value	Pr > F	
BLOCK	3	0.373	0.124	0.840	0.503		BLOCK	3	0.806	0.269	0.490	0.698	
GENO	3	17.683	5.894	40.110	0.0001		GENO	4	9.988	2.497	4.520	0.0186	
Source	DF	Type III SS	Mean Square	F Value	Pr > F		Source	DF	Type III SS	Mean Square	F Value	Pr > F	
BLOCK	3	0.373	0.124	0.840	0.503		BLOCK	3	0.806	0.269	0.490	0.698	
GENO	3	17.683	5.894	40.110	0.0001		GENO	4	9.988	2.497	4.520	0.0186	
R-Square	C.V.	Root MSE			RAT Mean		R-Square	C.V.	Root MSE		RAT Mean		
0.932	8.222	0.383			4.663		0.619	20.565	0.743		3.615		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

----- Table 45A

APPENDIX

Table 45B-----

ENV=6 TRT=1						ENV=6 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	5.655	0.943	5.450	0.0122	Model	7	2.078	0.297	1.000	0.4740
Error	9	1.555	0.173			Error	12	3.548	0.296		
Corrected Total	15	7.210				Corrected Total	19	5.626			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.340	0.113	0.660	0.599	BLOCK	3	0.050	0.017	0.060	0.982
GENO	3	5.315	1.772	10.250	0.0029	GENO	4	2.028	0.507	1.710	0.2112
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.340	0.113	0.660	0.599	BLOCK	3	0.050	0.017	0.060	0.982
GENO	3	5.315	1.772	10.250	0.0029	GENO	4	2.028	0.507	1.710	0.2112
R-Square	0.784					R-Square					
		C.V.	Root MSE		RAT Mean		C.V.	Root MSE		RAT Mean	
		22.776	0.416		1.825		29.156	0.544		1.865	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 46A

APPENDIX

Table 46B-----

-- ENV=6 TRT=2						- ENV=6 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	18.095	3.016	8.860	0.0023	Model	7	4.046	0.578	10.250	0.0005
Error	9	3.063	0.340			Error	11	0.620	0.056		
Corrected Total	15	21.158				Corrected Total	18	4.666			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	3.308	1.103	3.240	0.075	BLOCK	3	0.251	0.084	1.480	0.273
GENO	3	14.788	4.929	14.490	0.0009	GENO	4	3.795	0.949	16.820	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	3.308	1.103	3.240	0.075	BLOCK	3	0.231	0.077	1.370	0.304
GENO	3	14.788	4.929	14.490	0.0009	GENO	4	3.795	0.949	16.820	0.0001
R-Square	0.855					R-Square	0.867				
C.V.	14.909					C.V.	7.558				
Root MSE		0.583				Root MSE		0.237			
							</				

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 47A

APPENDIX

Table 47B

ENV=7 TRT=1						ENV=7 TRT=1					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	16.132	2.689	4.190	0.0333	Model	7	4.205	0.601	5.590	0.0060
Error	8	5.137	0.642			Error	11	1.182	0.107		
Corrected Total	14	21.269				Corrected Total	18	5.387			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.520	0.173	0.270	0.845	BLOCK	3	0.345	0.115	1.070	0.401
GENO	3	15.612	5.204	8.100	0.0083	GENO	4	3.860	0.965	8.980	0.0018
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.198	0.066	0.100	0.956	BLOCK	3	0.268	0.089	0.830	0.504
GENO	3	15.612	5.204	8.100	0.0083	GENO	4	3.860	0.965	8.980	0.0018
R-Square	0.758					R-Square	0.781				
		33.482						Root MSE			
			0.801					C.V.			
				2.393				16.788			
								0.328			
										RAT Mean	
										1.953	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 48A

APPENDIX

Table 48B-----

			-- ENV=7 TRT=2 --						- ENV=7 TRT=2 -		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	15.585	2.598	7.370	0.0045	Model	7	13.591	1.942	6.760	0.0021
Error	9	3.173	0.353			Error	12	3.447	0.287		
Corrected Total	15	18.758				Corrected Total	19	17.038			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	1.963	0.654	1.860	0.208	BLOCK	3	0.738	0.246	0.860	0.490
GENO	3	13.623	4.541	12.880	0.0013	GENO	4	12.853	3.213	11.190	0.0005
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	1.963	0.654	1.860	0.208	BLOCK	3	0.738	0.246	0.860	0.490
GENO	3	13.623	4.541	12.880	0.0013	GENO	4	12.853	3.213	11.190	0.0005
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.831	14.525	0.594	4.088			0.798	15.269	0.536	3.510		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 49A

APPENDIX

Table 49B-----

-- ENV=8 TRT=1						- ENV=8 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	27.755	4.626	49.860	0.0001	Model	7	7.934	1.133	17.160	0.0001
Error	8	0.742	0.093			Error	11	0.727	0.066		
Corrected Total	14	28.497				Corrected Total	18	8.661			
Type I SS						Type I SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.836	0.279	3.000	0.095	BLOCK	3	0.074	0.025	0.370	0.775
GENO	3	26.919	8.973	96.720	0.0001	GENO	4	7.861	1.965	29.750	0.0001
Type III SS						Type III SS					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
BLOCK	3	0.669	0.223	2.410	0.143	BLOCK	3	0.111	0.037	0.560	0.653
GENO	3	26.919	8.973	96.720	0.0001	GENO	4	7.861	1.965	29.750	0.0001
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.974	9.101	0.305	3.347			0.916	13.057	0.257	1.968		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 50A

APPENDIX

Table 50B-----

-- ENV=8 TRT=2						- ENV=8 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	10.742	1.790	7.890	0.0051	Model	7	14.573	2.082	26.950	0.0001
Error	8	1.815	0.227			Error	12	0.927	0.077		
Corrected Total	14	12.557				Corrected Total	19	15.500			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.501	0.167	0.740	0.560	BLOCK	3	0.208	0.069	0.900	0.471
GENO	3	10.242	3.414	15.050	0.0012	GENO	4	14.365	3.591	46.490	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.510	0.170	0.750	0.553	BLOCK	3	0.208	0.069	0.900	0.471
GENO	3	10.242	3.414	15.050	0.0012	GENO	4	14.365	3.591	46.490	0.0001
R-Square	0.855					R-Square					
		Root MSE	0.476					Root MSE			
				RAT Mean	4.687					RAT Mean	
	</										

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 51A

APPENDIX

Table 51B

-- ENV=9 TRT=1						- ENV=9 TRT=1 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	12.565	2.094	38.270	0.0001	Model	7	13.012	1.859	1.120	0.4129
Error	9	0.493	0.055			Error	12	19.978	1.665		
Corrected Total	15	13.058				Corrected Total	19	32.990			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.073	0.024	0.440	0.729	BLOCK	3	0.950	0.317	0.190	0.901
GENO	3	12.493	4.164	76.100	0.0001	GENO	4	12.062	3.016	1.810	0.1915
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.073	0.024	0.440	0.729	BLOCK	3	0.950	0.317	0.190	0.901
GENO	3	12.493	4.164	76.100	0.0001	GENO	4	12.062	3.016	1.810	0.1915
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.962	11.624	0.234	2.013			0.394	57.219	1.290	2.255		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 52A

APPENDIX

Table 52B

-- ENV=9 TRT=2						- ENV=9 TRT=2 --					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6.700	1.117	5.230	0.0139	Model	7	7.791	1.113	7.810	0.0011
Error	9	1.920	0.213			Error	12	1.711	0.143		
Corrected Total	15	8.620				Corrected Total	19	9.502			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.545	0.182	0.850	0.500	BLOCK	3	0.914	0.305	2.140	0.149
GENO	3	6.155	2.052	9.620	0.0036	GENO	4	6.877	1.719	12.060	0.0004
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.545	0.182	0.850	0.500	BLOCK	3	0.914	0.305	2.140	0.149
GENO	3	6.155	2.052	9.620	0.0036	GENO	4	6.877	1.719	12.060	0.0004
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.777	10.741	0.462	4.300			0.820	10.697	0.378	3.530		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 53A

APPENDIX

Table 53B

-- ENV=10 TRT=1						- ENV=10 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	17.904	2.984	9.730	0.0026	Model	7	2.044	0.292	2.140	0.1247
Error	8	2.452	0.307			Error	11	1.500	0.136		
Corrected Total	14	20.356				Corrected Total	18	3.544			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.251	0.084	0.270	0.843	BLOCK	3	0.997	0.332	2.440	0.120
GENO	3	17.653	5.884	19.200	0.0005	GENO	4	1.048	0.262	1.920	0.1771
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.202	0.067	0.220	0.880	BLOCK	3	1.020	0.340	2.490	0.114
GENO	3	17.653	5.884	19.200	0.0005	GENO	4	1.048	0.262	1.920	0.1771
R-Square	0.880	C.V.	22.691	Root MSE	0.554	R-Square	0.577	C.V.	23.624	Root MSE	0.369
						RAT Mean 1.563					

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 54A

APPENDIX

Table 54B-----

-- ENV=10 TRT=2						- ENV=10 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	16.474	2.746	4.000	0.0578	Model	7	8.655	1.236	3.080	0.0422
Error	6	4.115	0.686			Error	12	4.823	0.402		
Corrected Total	12	20.589				Corrected Total	19	13.478			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	4.362	1.454	2.120	0.199	BLOCK	3	1.590	0.530	1.320	0.314
GENO	3	12.112	4.037	5.890	0.0321	GENO	4	7.065	1.766	4.390	0.0204
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	4.426	1.475	2.150	0.195	BLOCK	3	1.590	0.530	1.320	0.314
GENO	3	12.112	4.037	5.890	0.0321	GENO	4	7.065	1.766	4.390	0.0204
R-Square	0.800	C.V.	21.278	Root MSE	0.828	R-Square	0.642	C.V.	17.733	Root MSE	0.634
				RAT Mean						RAT Mean	
				3.892						3.575	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-- ENV=11 TRT=1						- ENV=11 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	23.674	3.946	13.980	0.0004	Model	7	19.271	2.753	11.480	0.0002
Error	9	2.541	0.282			Error	12	2.877	0.240		
Corrected Total	15	26.214				Corrected Total	19	22.148			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	1.447	0.482	1.710	0.234	BLOCK	3	3.348	1.116	4.650	0.022
GENO	3	22.227	7.409	26.250	0.0001	GENO	4	15.923	3.981	16.600	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	1.447	0.482	1.710	0.234	BLOCK	3	3.348	1.116	4.650	0.022
GENO	3	22.227	7.409	26.250	0.0001	GENO	4	15.923	3.981	16.600	0.0001
R-Square	C.V.	Root MSE		RAT Mean		R-Square	C.V.	Root MSE		RAT Mean	
0.903	19.190	0.531		2.769		0.870	21.666	0.490		2.260	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-- ENV=11 TRT=2						- ENV=11 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	14.918	2.486	35.840	0.0001	Model	7	10.706	1.529	10.670	0.0003
Error	8	0.555	0.069			Error	12	1.720	0.143		
Corrected Total	14	15.473				Corrected Total	19	12.426			
-- ENV=11 TRT=2						- ENV=11 TRT=2 -					
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.863	0.954	13.760	0.002	BLOCK	3	0.418	0.139	0.970	0.438
GENO	3	12.055	4.018	57.920	0.0001	GENO	4	10.288	2.572	17.940	0.0001
-- ENV=11 TRT=2						- ENV=11 TRT=2 -					
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.769	0.256	3.700	0.062	BLOCK	3	0.418	0.139	0.970	0.438
GENO	3	12.055	4.018	57.920	0.0001	GENO	4	10.288	2.572	17.940	0.0001
R-Square	0.964					R-Square	0.862				
C.V.	6.477					C.V.	11.251				
Root MSE	0.263					Root MSE	0.379				
RAT Mean	4.067					RAT Mean	3.365				

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 57A

APPENDIX

Table 57B

-- ENV=12 TRT=1						- ENV=12 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	5.974	0.996	4.480	0.0225	Model	7	31.101	4.443	14.370	0.0001
Error	9	2.001	0.222			Error	12	3.709	0.309		
Corrected Total	15	7.974				Corrected Total	19	34.810			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.762	0.254	1.140	0.383	BLOCK	3	6.854	2.285	7.390	0.005
GENO	3	5.212	1.737	7.820	0.0071	GENO	4	24.247	6.062	19.610	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.762	0.254	1.140	0.383	BLOCK	3	6.854	2.285	7.390	0.005
GENO	3	5.212	1.737	7.820	0.0071	GENO	4	24.247	6.062	19.610	0.0001
R-Square	0.749	23.948				R-Square	0.893	23.117			
			Root MSE	0.471					Root MSE	0.556	
					RAT Mean					RAT Mean	
					1.969					2.405	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 58A

APPENDIX

Table 58B-----

-- ENV=12 TRT=2						- ENV=12 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	5.249	0.875	5.470	0.0158	Model	7	3.896	0.557	1.660	0.2092
Error	8	1.280	0.160			Error	12	4.014	0.335		
Corrected Total	14	6.529				Corrected Total	19	7.910			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.915	0.305	1.910	0.207	BLOCK	3	0.414	0.138	0.410	0.747
GENO	3	4.334	1.445	9.030	0.0060	GENO	4	3.482	0.871	2.600	0.0893
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.925	0.308	1.930	0.204	BLOCK	3	0.414	0.138	0.410	0.747
GENO	3	4.334	1.445	9.030	0.0060	GENO	4	3.482	0.871	2.600	0.0893
R-Square	0.804					R-Square	0.493				
						C.V.	17.290				
						Root MSE	0.578				
										RAT Mean	3.345

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-slab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 59A

APPENDIX

Table 59B

-- ENV=13 TRT=1						- ENV=13 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	24.155	4.026	7.450	0.0362	Model	7	15.571	2.224	12.160	0.0001
Error	4	2.161	0.540			Error	12	2.195	0.183		
Corrected Total	10	26.316				Corrected Total	19	17.766			
-- ENV=13 TRT=1						- ENV=13 TRT=1 -					
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	10.578	3.526	6.530	0.051	BLOCK	3	0.198	0.066	0.360	0.783
GENO	3	13.577	4.526	8.380	0.0337	GENO	4	15.373	3.843	21.010	0.0001
-- ENV=13 TRT=1						- ENV=13 TRT=1 -					
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	15.625	5.208	9.640	0.027	BLOCK	3	0.198	0.066	0.360	0.783
GENO	3	13.577	4.526	8.380	0.0337	GENO	4	15.373	3.843	21.010	0.0001
R-Square	0.918	23.574				R-Square	0.876				
			Root MSE	0.735				Root MSE		RAT Mean	
										2.365	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 60A

APPENDIX

Table 60B-----

-- ENV=13 TRT=2						- ENV=13 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	16.846	2.808	124.790	0.0684	Model	7	4.668	0.667	17.490	0.0001
Error	1	0.023	0.023			Error	11	0.420	0.038		
Corrected Total	7	16.869				Corrected Total	18	5.087			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.297	0.766	34.030	0.125	BLOCK	3	0.644	0.215	5.630	0.014
GENO	3	14.549	4.850	215.540	0.0500	GENO	4	4.024	1.006	26.380	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	5.805	1.935	86.000	0.079	BLOCK	3	0.682	0.227	5.960	0.012
GENO	3	14.549	4.850	215.540	0.0500	GENO	4	4.024	1.006	26.380	0.0001
R-Square	0.999	C.V.	Root MSE	RAT Mean		R-Square	0.918	Root MSE	RAT Mean		
		3.419	0.150	4.388			7.108	0.195	2.747		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 61A

APPENDIX

Table 61B-----

-- ENV=14 TRT=1						- ENV=14 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	12.442	2.074	12.500	0.0036	Model	7	36.823	5.260	22.650	0.0001
Error	6	0.995	0.166			Error	12	2.787	0.232		
Corrected Total	12	13.437				Corrected Total	19	39.610			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.129	0.043	0.260	0.852	BLOCK	3	0.166	0.055	0.240	0.869
GENO	3	12.312	4.104	24.740	0.0009	GENO	4	36.657	9.164	39.460	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.820	0.273	1.650	0.276	BLOCK	3	0.166	0.055	0.240	0.869
GENO	3	12.312	4.104	24.740	0.0009	GENO	4	36.657	9.164	39.460	0.0001
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.926	12.667	0.407	3.215			0.930	13.789	0.482	3.495		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 62A

APPENDIX

Table 62B-----

-- ENV=14 TRT=2						- ENV=14 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	4	8.773	2.193	17.900	0.1752	Model	7	3.009	0.430	0.580	0.7562
Error	1	0.123	0.123			Error	7	5.200	0.743		
Corrected Total	5	8.895				Corrected Total	14	8.209			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.270	0.757	6.180	0.286	BLOCK	3	1.597	0.532	0.720	0.573
GENO	1	6.503	6.503	53.080	0.0868	GENO	4	1.412	0.353	0.480	0.7538
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.103	0.034	0.280	0.845	BLOCK	3	1.614	0.538	0.720	0.569
GENO	1	6.503	6.503	53.080	0.0868	GENO	4	1.412	0.353	0.480	0.7538
R-Square	0.986					R-Square					
		C.V.	6.422					C.V.			
		Root MSE	0.350					Root MSE	0.862		
										RAT Mean	3.793

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 63A

APPENDIX

Table 63B

-- ENV=15 TRT=1						- ENV=15 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	13.914	2.319	21.680	0.0002	Model	7	11.173	1.596	7.050	0.0018
Error	8	0.856	0.107			Error	12	2.715	0.226		
Corrected Total	14	14.769				Corrected Total	19	13.888			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	2.505	0.835	7.810	0.009	BLOCK	3	1.900	0.633	2.800	0.085
GENO	3	11.409	3.803	35.560	0.0001	GENO	4	9.273	2.318	10.250	0.0008
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	2.946	0.982	9.180	0.006	BLOCK	3	1.900	0.633	2.800	0.085
GENO	3	11.409	3.803	35.560	0.0001	GENO	4	9.273	2.318	10.250	0.0008
R-Square	C.V.	Root MSE	RAT Mean			R-Square	C.V.	Root MSE	RAT Mean		
0.942	12.610	0.327	2.593			0.805	19.494	0.476	2.440		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 64A

APPENDIX

Table 64B

-- ENV=15 TRT=2						- ENV=15 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	3.834	0.639	2.670	0.1000	Model	7	2.847	0.407	4.750	0.0136
Error	8	1.916	0.239			Error	10	0.856	0.086		
Corrected Total	14	5.749				Corrected Total	17	3.703			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.534	0.178	0.740	0.555	BLOCK	3	1.384	0.461	5.390	0.018
GENO	3	3.299	1.100	4.590	0.0376	GENO	4	1.463	0.366	4.270	0.0285
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.529	0.176	0.740	0.559	BLOCK	3	1.026	0.342	3.990	0.042
GENO	3	3.299	1.100	4.590	0.0376	GENO	4	1.463	0.366	4.270	0.0285
R-Square	0.667					R-Square					
		C.V.	15.751					C.V.			
		Root MSE	0.489					Root MSE			
				RAT Mean	3.107					RAT Mean	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

-----Table 65A

APPENDIX

Table 65B-----

-- ENV=16 TRT=1						- ENV=16 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6.837	1.140	8.350	0.0043	Model	7	21.743	3.106	23.190	0.0001
Error	8	1.092	0.137			Error	12	1.607	0.134		
Corrected Total	14	7.929				Corrected Total	19	23.350			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.104	0.035	0.250	0.856	BLOCK	3	1.426	0.475	3.550	0.048
GENO	3	6.733	2.244	16.440	0.0009	GENO	4	20.317	5.079	37.930	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.129	0.043	0.320	0.814	BLOCK	3	1.426	0.475	3.550	0.048
GENO	3	6.733	2.244	16.440	0.0009	GENO	4	20.317	5.079	37.930	0.0001
R-Square	0.862	C.V.	18.232			R-Square	0.931	C.V.	14.323		
		Root MSE	0.369	RAT Mean	2.027			Root MSE	0.366	RAT Mean	2.555

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 66A

APPENDIX

Table 66B

-- ENV=16 TRT=2			- ENV=16 TRT=2 -		
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	5.964	0.994	0.880	0.5433
Error	9	10.121	1.125		
Corrected Total	15	16.084			
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	3.497	1.166	1.040	0.422
GENO	3	2.467	0.822	0.730	0.5589
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	3.497	1.166	1.040	0.422
GENO	3	2.467	0.822	0.730	0.5589
R-Square	0.371	C.V.	Root MSE	RAT Mean	
		35.570	1.060	2.981	
Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	1.058	0.353	4.830	0.020
GENO	4	5.193	1.298	17.800	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	1.058	0.353	4.830	0.020
GENO	4	5.193	1.298	17.800	0.0001
R-Square	0.877	C.V.	Root MSE	RAT Mean	
		7.861	0.270	3.435	

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

Table 67A

APPENDIX

Table 67B

-- ENV=17 TRT=1						- ENV=17 TRT=1 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	29.517	4.920	24.910	0.0001	Model	7	45.701	6.529	28.110	0.0001
Error	8	1.580	0.198			Error	12	2.787	0.232		
Corrected Total	14	31.097				Corrected Total	19	48.488			
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	0.312	0.104	0.530	0.676	BLOCK	3	1.368	0.456	1.960	0.173
GENO	3	29.205	9.735	49.290	0.0001	GENO	4	44.333	11.083	47.720	0.0001
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	0.162	0.054	0.270	0.843	BLOCK	3	1.368	0.456	1.960	0.173
GENO	3	29.205	9.735	49.290	0.0001	GENO	4	44.333	11.083	47.720	0.0001
R-Square	0.949	Root MSE	0.444	RAT Mean	2.847	R-Square	0.943	Root MSE	0.482	RAT Mean	3.340
		C.V.	15.612					C.V.	14.429		

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

- ENV=17 TRT=2 -						- ENV=17 TRT=2 -					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F	Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	6	6.594	1.099	4.790	0.0230	Model	7	2.463	0.352	3.880	0.0193
Error	8	1.836	0.229			Error	12	1.087	0.091		
Corrected Total	14	8.429				Corrected Total	19	3.550			
- ENV=17 TRT=2 -						- ENV=17 TRT=2 -					
Source	DF	Type I SS	Mean Square	F Value	Pr > F	Source	DF	Type I SS	Mean Square	F Value	Pr > F
BLOCK	3	1.155	0.385	1.680	0.248	BLOCK	3	0.746	0.249	2.740	0.089
GENO	3	5.439	1.813	7.900	0.0089	GENO	4	1.717	0.429	4.740	0.0159
- ENV=17 TRT=2 -						- ENV=17 TRT=2 -					
Source	DF	Type III SS	Mean Square	F Value	Pr > F	Source	DF	Type III SS	Mean Square	F Value	Pr > F
BLOCK	3	1.626	0.542	2.360	0.147	BLOCK	3	0.746	0.249	2.740	0.089
GENO	3	5.439	1.813	7.900	0.0089	GENO	4	1.717	0.429	4.740	0.0159
R-Square	0.782	C.V.	15.485	Root MSE	0.479	R-Square	0.694	C.V.	10.185	Root MSE	0.301
										RAT Mean	2.955

Analyses of variance for grain yields (VAR5) or ear rot ratings (RAT) on inbred lines (A) and hybrids (B) with the silk channel (TRT=1) and the kernel-stab (TRT=2) inoculations on 17 environments (ENV=1 to ENV=17).

APPENDIX

Table 69.

Regression analysis for the best 2-variable model between environmental factors using the Statistical Analysis System's Stepwise procedure. Independent variables include the number of monthly cool and wet days during July to September (COL1-COL3); number of days with high relative humidity (HUM1-HUM3); monthly rainfall (RN1-RN3), for dependent variable ear rot rating with silk channel inoculation.

	DF	SS	MS	F-value	P
Regression	2	1.3643	0.6822	4.73	0.036
Error	10	1.4408	0.1441		
Total	12	2.8051			
	Parameter Estimate	Standard Error	Type II Sum of Squares	F	P
VARIABLES					
Intercept	3.0035	0.5950	3.6739	25.50	0.001
COL2	-0.0798	0.0418	0.5263	3.65	0.085
RN3	0.00402	0.0033	0.2098	1.46	0.255
Bounds on condition number:		1.2952	5.1807		

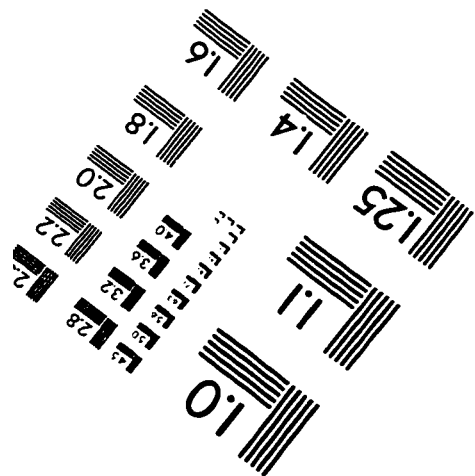
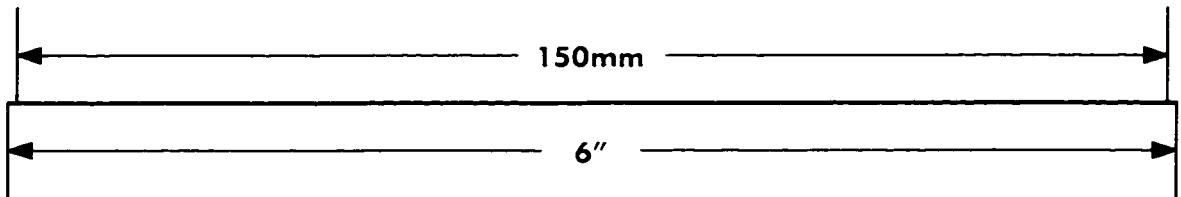
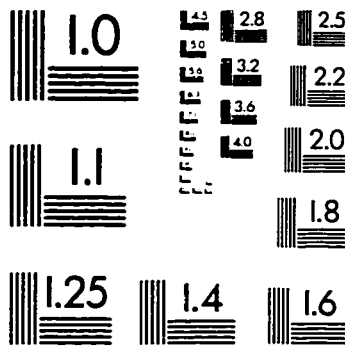
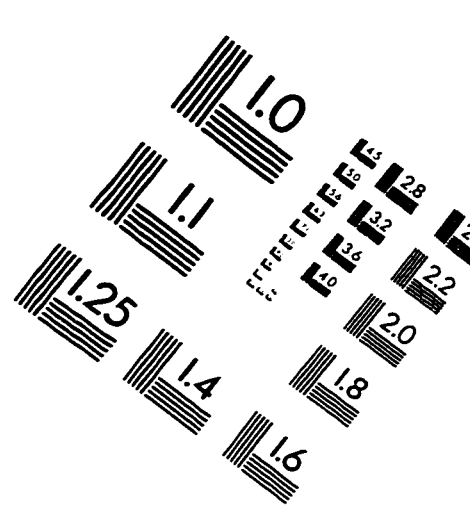
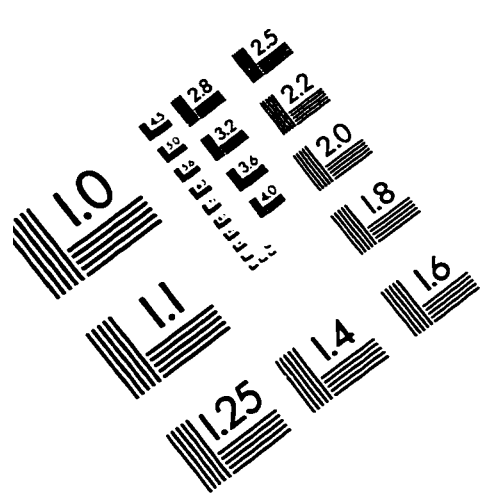
APPENDIX

Table 70.

Regression analysis for the best 2-variable model between environmental factors using the Statistical Analysis System's Stepwise procedure. Independent variables include the number of monthly cool and wet days during July to September (COL1-COL3); number of days with high relative humidity (HUM1-HUM3); monthly rainfall (RN1-RN3), for dependent variables grain dry weight with kernel-stab inoculation.

	DF	SS	MS	F-value	P
Regression	2	1421.5159	710.7579	3.27	0.081
Error	10	2173.0055	217.3006		
Total	12	3594.5214			
	Parameter Estimate	Standard Error	Type II Sum of Squares	F	P
VARIABLES					
Intercept	116.5201	21.9870	6102.8026	28.08	0.001
COL2	-3.0848	1.4346	1004.7222	4.62	0.057
RN3	-1.0674	0.9522	273.0490	1.26	0.289
Bounds on condition number:		1.0142	4.0567		

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