FACTORS INFLUENCING THE DEVELOPMENT OF SEPTORIA BLIGHT IN CELERY

by

(c) Edgar Martinez Granja

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Department of Plant Science
Faculty of Agricultural and Environmental Sciences
McGill University
Montreal, Quebec, Canada

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ABSTRACT

Ph.D. Edgar Martinez Granja Plant Science

FACTORS INFLUENCING THE DEVELOPMENT OF SEPTORIA BLIGHT IN CELERY

Septoria blight of celery (Apium graveolens) caused by Septoria apiicola is a common disease. This work dealt with the development of a simple forecast model to time fungicide application to manage the blight. Two studies were conducted to examine the effect of relative humidity (65, 88, 92, 96%, and wet) temperature (15, 20, 25, and 28 C) and exposure period (6, 12, 24, 48, 72, and 96 hr) on spore production. Spores were produced at all levels of relative humidity and temperature tested. Overall spore production increased with increasing relative humidity. The greatest and the least were produced after a 48 hr wet period at 20 and 28 C, respectively. Two regression models were developed to predict spore production as functions of relative humidity and temperature. In order to validate the infection function model a field experiment was conducted in 1989 to quantify latent period. A mean latent period beginning of 12 days, a mean latent period 50% of 14 days, and a mean latent period ending of 19 days were established. Two regression models were developed to predict latent period beginning and latent

period ending as functions of mean maximum and mean minimum temperatures. In order to develop a simple forecast model field experiments were conducted in 1989 and 1990. From these studies two simple forecast models are proposed to initiate fungicide applications: 1) Initial disease occurrence. 2) A cumulative disease severity value (CDSV) of 23. Using the forecasts proposed it is possible to reduce five to seven applications of fungicides during the celery growing season in Quebec.

RESUME

Ph.D. Edgar Martinez Granja Plant Science

FACTEURS INFLUENCANT LE DEVELOPPEMENT DE LA SEPTORIA CHEZ LE CELERI

La "septoria" chez le céleri (Apium graveolens) causée par la Septoria apiicola est une maladie fréquente. Cette thèse traite au développement d'un modèle prévisionnel simple pour établir la fréquence d'application de fongicides afin de contrôler le champignon. Deux études ont été menées pour vérifier l'effet de l'humidité relative (65 %, 88 %, 92 %, 96 % et humide) et de la température (15, 20, 25 et 28 degrés C) et ce, à une période d'exposition (de 6, 12, 24, 48, 72 et 96 h) sur la production du spore. La production de spores s'est produite à tous les degrés d'humidité relative et de température vérifiée. L'ensemble de la production des spores s'est accrue avec l'augmentation de l'humidité relative. La production du nombre de spores le plus élevé et le plus bas a eu lieu après avoir enregistré une période d'humidité de 48 h à des températures de 20 et 28 degrés C, respectivement. Deux modèles de régression ont été mis au point afin de prédire la production de spores comme facteur d'humidité relative et de température. Afin de confirmer une infection qui s'est développée antérieurement,

une expérience sur le terrain a été menée en 1989 pour quantifier la période latente. Les périodes suivantes ont été établies : une période latente moyenne initiale de 12 jours, une période latente moyenne de
14 jours à 50 % et une période latente moyenne finale de 19 jours. Deux modèles de régresssion ont été conçus pour prédire la période latente initiale et finale comme température minimale et maximale. Pour concevoir un modèle prévisionnel simple, des expériences sur le terrain ont été effectuées en 1989 et 1990. Selon ces études, il est proposé deux modèles simples pour prévoir le commencement de l'application de fongicide : 1) l'apparition du début de la maladie et 2) un niveau de maladie cumulative avancée (CDSV) atteignant 23. Grâce à l'utilisation des prévisions proposées, l'application de fongicide peut être réduite de cinq à sept pendant la période de culture du céleri au Québec.

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

INTRODUCTION

A wide spectrum of diseases are encountered in the production of celery. These diseases continually threaten the yield of this important vegetable. Late blight induced by Septoria apiicola Speg. is one of the major constraints in celery production. Chemical control has been the most common method utilized in the management of the disease. Fungicides are applied at 7-10 day intervals. However, concerns about the environment and possible health risks have increased the need to reduce fungicide application through a disease management program. In order to develop such a program it is necessary to have an in-depth knowledge of the factors influencing the onset and development of the disease. To date, no quantification of the components of a late blight epidemic, as affected by weather factors, has been carried out. A detailed study of the factors influencing infection, sporulation, and dissemination is required to develop a fundamental forecasting system.

The general objective of this research was to identify certain important factors which influence the development of septoria blight in celery in order to formulate a forecasting system to time fungicide application.

The specific objectives were 1) to study the effect of temperature and relative humidity on spore production and to

develop models to predict spore production based on temperature and relative humidity; 2) to quantify latent period and to develop a model to predict latent period from temperature; 3) to propose a simple forecast model to time fungicide applications.

LITERATURE REVIEW

CELERY PRODUCTION. Celery (Apium graveolens var dulce, Pers.) is produced in various provinces in Canada with an estimated value farm gate of $13.2 million dollars and a production area of 797 ha for 1990. Quebec grew 406 ha with a value of $5.4 millions in 1989 (Anonymous, 1991). Like other crops, celery yield is affected by biotic and abiotic factors, among which diseases caused by fungi, bacteria, nematodes, and virus are of particular importance. Major fungal diseases of celery include those caused by Septoria apiicola, Fusarium oxysporum, Pythium spp., Rhizoctonia solani, Sclerotinia sclerotiorum, Sclerotium rolfsii, and Cercospora apii (Bant and Storey, 1952; Berger, 1970; Benedict, 1973; Dixon, 1988; Nonnecke, 1989). Such a wide spectrum of diseases has stimulated the development of research focused on disease resistance, exclusion and eradication measures and the development of forecast models to time fungicide application (Strandberg, 1982; Nonnecke, 1989).

GENERAL ASPECTS OF SEPTORIA BLIGHT. The disease known as Septoria blight or late blight was first described in Italy in 1890. This blight is now present wherever celery is

cultivated (Anonymous, 1966; Sherf and Macnab, 1986).

Importance. The disease causes reduction in plant growth and has a direct effect on the quality of the final product. The costs of chemical control also affect the market value reducing the income of the growers. It is considered the most harmful disease of celery and losses of up to 90% in commercial fields have been reported (Anonymous, 1966; Sheridan, 1966; Dixon, 1978; Sherf and Macnab, 1986).

Symptoms. The first symptoms develop as circular yellow areas which gradually change size and turn brown, ringed by dark margins and chlorotic halos. Inside the lesions, in the necrotic tissue it is possible to see the pycnidia. Lesions are usually circular, but it is possible to find irregular shapes depending on the age and coalescence of lesions as well as on the development of spots close to veins of the leaf. The pathogen first infects the older leaves of both seedlings and adult plants. From the older leaves late blight spreads to the whole plant including petioles (Gabrielson and Grogan, 1964; Anonymous, 1966; Simms et al, 1977; Sherf and Macnab, 1986).

Pathogen. Septoria blight is caused by Septoria apiicola Speg, which is one of the most harmful of the

Septoria spp, and is the only species pathogenic to celery (Anonymous, 1966; Benedict, 1973). This fungus belongs to the subdivision Deuteromycotina and the order Sphaeropsidales, family Sphaeropsidaceae (Alexopoulos and Mims, 1979). The sexual stage is unknown. An asexual stage is commonly found. The pycnidium is present in all affected tissues. It is dark, with ostiole rounded to irregular, and it is considered to be mature if an open pore can be observed (Gabrielson and Grogan, 1964; Alexopoulos and Mims, 1979). Pycnidia swell with the absorption of water and after a period of time expel a cirrhus of spores. This cirrhus is white to tan in colour, is slimy and prevents the removal of spores by wind. Once in contact with water the spores are released immediately permitting germination. Water is, therefore, an important factor in the spread of the disease (MacMillan, 1942; Louis and Cooke, 1985; Fitt and McCartney, 1986; Fitt et al, 1989). The spores are hyaline, filiform, straight to curved. The number of septa varies from 0 to 7. At maturity the spores have a minimum of 3 septa and are ready to leave the pycnidium under optimum environmental conditions. The presence of more than 3 septa is an indication that a spore is growing and will germinate within a few hours (MacMillan, 1942).

FACTORS INFLUENCING DISEASE DEVELOPMENT. Epidemics are

dynamic and complex biological processes that develop in space and time. They express the development and behaviour of the parasitic relationship between pathogen and host as influenced by the pattern of field environmental conditions where the crop develops (Zadoks and Schein, 1979). The epidemic consists of processes called infection cycles. Each infection cycle starts with one infection unit and ends with the production of a new generation of infection units (Zadoks and Schein, 1979; Fry, 1982). The infection cycle consists in its turn of a number of subprocesses such as infection, sporulation, and dissemination. In each subprocess the pathogen presents specific features according to the host and environmental conditions. To allow their complete examination and quantification, the subprocess can be subdivided into smaller phases according to the growth of the pathogen (Zadoks, 1978; Zadoks and Schein, 1979; Campbell and Madden, 1990). Thus the rate of disease development, the polycyclic process, depends on the amount of initial inoculum and the factors influencing the various subprocesses.

Inoculum. There are two main sources of inoculum from which seedlings and adult plants of a new crop become infected in the field, namely, infected crop debris and infected seeds (Linn, 1939; Sheridan, 1966; Sherf and Macnab, 1986). The effect of infected crop debris on disease

spread in the same field depends on the survival of the spores of the pathogen under field conditions and on the time interval between incorporation of previous crop debris into soil and the planting of the next crop. Based on these factors it is generally recommended that celery crop debris be incorporated into the soil 21 months in advance of a new celery planting or to practice an adequate rotation in order to reduce the risk of new infection (Sheridan, 1966; Maude and Shuring, 1970).

Seeds are also an important vehicle for dispersal of the pathogen and disease spread. Viable spores are carried on the seed and mycelium may be found in testa. Seed-borne spores have been found to be the major cause for seedling infection (Sheridan, 1966; Hewett, 1968; Maude, 1970) The amount of infection depends on the viability of the expelled spores which in turn depend on the age of pycnidia and seed storage temperature. Seed-borne spores remain viable for a period of 15 months. However, at -10 C for 18 months the ability of spores to cause infection is high. At a temperature range of 11-18 C the number of pycnidia expelling spores declined approximately by 90% in 4-6 months, and to zero after 12 months, with a corresponding reduction in the ability to infect (Hewett, 1968; Sheridan, 1968a; Maude and Shuring, 1970; Sherf and Macnab, 1986).

Infection. Septoria apiicola spores germinate,

penetrate directly into leaves or petioles and mycelia grows intercellularly throughout the whole leaf (Benedict, 1973; Dixon, 1978; Sherf and Macnab, 1986; Dixon, 1988). Spore germination is weather dependent and environmental conditions play an important role in S. apiicola development. Spores germinate and penetrate the leaf tissue under high relative humidity not less than 90% for 48 hr or free moisture for at least 24 hours at temperatures between 20 and 25 C (Gabrielson and Grogan, 1964; Sheridan, 1968a). Temperature is not a limiting factor for spore germination because they can germinate within a temperature range of about 12 to 28 C (Sherf and Macnab, 1986). For successful infection, a period of 36-72 hours of continuous high humidity at 15-17 C is required (Gabrielson and Grogan, 1964; Sheridan, 1968b; Berger, 1970). However, at optimum temperature and relative humidity the germination is inversely related to spore concentration, the higher the spore concentration the lower the germination. This effect is attributed to the presence of a germination inhibitor in the matrix of the cirri (Berger, 1970; Louis and Cooke, 1985). However, the increase in the number of lesions produced after inoculation is directly related to the increase in spore concentration (Sheridan, 1968b; Mudita and Kushalappa, 1991).

The infection subprocess may be described as a function of environmental factors such as temperature, relative

humidity and wetness employing regression models. Such models may be used in forecasting disease (Parlevliet, 1979; Turner et al, 1986; Butt and Royle, 1990). Regression models have been developed to predict infection of soybean leaves and seeds by Phomopsis longicolla (TeKrony et al, 1983; Rupe and Ferris, 1987) and of carrot leaves by Cercospora carotae (Carisse and Kushalappa, 1990).

Latent Period. Latent period (LP) is a period of time from infection until new lesions produced become infectious (Zadoks, 1978; Parlevliet, 1979; Campbell and Madden 1990). It plays a major role in determining the infection rate. Normally, a shorter LP results in an increase in the number of infection cycles during a cropping season and thus, a higher infection rate (Parlevliet, 1975; Shaner, 1980). The LP varies depending on temperature, moisture, age of the leaf, age of the plant, inoculum density and genotype (Parlevliet, 1975; Friesland and Schrodter, 1988). Under extreme temperatures the latent period could be lengthened, reducing the number of spore generations occurring during a season and reducing the rate of epidemic development (Colhoun, 1973; Rotem, 1978). Temperature as well as duration of leaf wetness influence the latent period of Septoria nodorum in wheat. It has been found that latent period is reduced by an increase in both temperature and wetness duration (Shearer and Zadoks, 1972, 1974). Under

experimental conditions the latent period of celery late blight varies between 7 to 14 days depending on temperature. At controlled temperatures between 20-25 C symptoms develop within 7-8 days, and for plants maintained at 28 C during part of the day symptom appearance was delayed to 14 days with lower disease severity (Berger, 1970; Simms et al, 1977; Sherf and Macnab, 1986). Under field conditions symptoms were visible 9-12 days after inoculation (Simms et al, 1977).

The measure of latent period applied to a population of lesions is important for forecasting purposes (Kranz, 1974; Shaner, 1980). Latent period can be measured based on daily counting of the number of lesions or pustules on the leaves. The number of pustules are counted until no more pustules appear and then the time in days until 50% are visible is calculated (Parlevliet, 1975). This procedure has been criticized because no information about the rate and the minimum latent period is available. Another method is a weighted average latent period, calculated on proportion of sporulating lesions (Shaner, 1980). In this method it is possible to predict latent period using multiple regression equations (Shearer and Zadoks, 1974).

Sporulation. Fungal spores are an important source of dispersal and infection units. Sporulation is a process inherent to a specific fungus. Each fungus has its own

specificity related to spore production, spore liberation, spore dispersal, and length of infectious period (Kranz, 1974; Populer, 1978; Dahlberg and Van Eten, 1982; Sherf and Macnab, 1986). Also, the stages involved in the sporulation subprocess are very complex and it becomes difficult to distinguish between them (Dahlberg and Van Etten, 1982).

The amount of spores produced is influenced by factors such as light, temperature, humidity, aeration, pH, injury to the culture, and nutrient type and media composition (Kranz, 1974; Dahlberg and Van Eten, 1982; Cohen and Rotem, 1984). Among these, temperature and moisture are considered to be most important in influencing spore production. These also influence spore viability, longevity, conidiophore formation, spore release, and infection (Colhoun, 1973; Strandberg, 1977; Turner et al, 1986). Generally under optimum temperature conditions the wetness duration and the frequency of wetness periods have the most important effect on fungal sporulation. Some fungi produce more spores at longer periods of both high relative humidity close to 100% and wetness. However, alternating wet/dry periods are also required for certain fungi to sporulate (Rotem, 1978; Cohen and Rotem, 1984; Royle and Butler, 1986). When held for 50 hr at 25 C, Septoria tritici produced spores at different levels of relative humidity but the number of spores produced at 100% relative humidity was twice as large as those at 98% relative humidity (Gough and Lee, 1985). In

some diseases a combination of either a higher temperature and short wetness period or a lower temperature and longer wetness period is optimum for fungal sporulation. However high temperature induces high spore production in the early stages of lesion development of some diseases (Cohen and Rotem, 1984). For example Phyllosticta maydis produces pycnidia and spores at temperatures ranging from 18 C to 27 C. However the production is higher at 18 C in 11 days than at 27 C after 5 days (Castor et al, 1977).

The sporulation models as functions of factors influencing them have been developed and used to account for variation in epidemics (Zadoks and Schein, 1979). Quantification and prediction of the sporulation subprocess has been modeled mainly on environmental factors such as temperature and relative humidity. The Richards function was used to predict the sporulation of Plasmopara viticola as a function of temperature and relative humidity (Lalancette et al, 1988). Also, multiple regression analysis has been used for this purpose. Mathematical models which predict sporulation are considered to be more efficient than spore trapping in disease management programs (Strandberg, 1977; Parlevliet, 1979; Turner et al, 1986; Butt and Royle, 1990).

Dispersal. Dispersal is an important factor in the development of a celery late blight epidemic. S. apiicola can be dispersed in the field by water droplets from

rainfall or overhead irrigation, by workers and implements (Linn, 1939; Berger, 1970; Simms et al, 1977; Sherf and Macnab, 1986). Among these agents of dispersal free water is critical when the spores released by a fungus are protected by cirri, as in S. apiicola. The cirri need contact with a wet surface to liberate and to disperse the spores on the leaf surface and within the plant (Sanderson and Hampton, 1978; Zadoks and Schein, 1979). There is not much information available related to the dispersal of spores of S. apiicola by splashing water, but there is no doubt about the importance of water in the spread of the disease and on the influence of wet weather on the increase of celery late blight intensity (Berger, 1970; Simms et al, 1977). As a matter of comparison, there are some studies which explain the dispersal of S. nodorum on wheat. Spores of S. nodorum were carried in droplets of water (200-400 µm diameter) and there was a significant relationship between number of spores per droplet and droplet diameter, and between number of spores collected and distance (Brennan et al, 1985).

Aerial dispersal of S. apiicola spores is unlikely (Berger, 1970), possibly because spores are slimy and so a direct wind removal does not occur (Ingold, 1978). But there is evidence of aerial dispersion of pycnidiospores of S. nodorum over wheat crops under rainy conditions. S. nodorum spores were caught in traps that were situated 50 cm away from the infected plants and at a height of 40 cm above

ground. The movement and direction of spores were not affected by wind below 40 cm above ground (Faulkner and Colhoun, 1976; Griffiths and Hann, 1976). It has been pointed out that when a combination of splash and wind is present spores may disperse over a long distances (Ingold, 1978). Overall, there is a need for more research on spore dispersal and its influence on disease development (McCartney and Fitt, 1987).

MODELS TO PREDICT DISEASE. In order to achieve efficient and economic disease control together with reduced hazards to the environment, it is imperative to understand the dynamics of the pathosystem. This is possible through a fundamental knowledge of disease epidemiology and, in particular, by the development of disease prediction models (Krause and Massie, 1975; Shrum, 1978; Fry, 1982). Disease prediction models enhance the knowledge of potential forecast parameters. They can be used to predict an increase in disease based on components of the epidemic (Campbell and Madden, 1990). Since not all of the components can be included in a model, disease prediction models may involve few or many parameters depending on their efficiency to predict disease (Kranz and Royle, 1978; Kushalappa, 1990). They, therefore, afford a quantitative description of plant disease, explain their components and their relation within

the plant pathosystem, which has an enormous significance to develop plant disease management programs (Fry, 1982). Regression analysis has been broadly used in developing prediction models (Kranz and Royle, 1978) to select good predictors for forecasting purposes, to describe a quantitative variation of a dependent variable, and to analyze the relationship between physical and biological factors within the pathosystem (Krause and Massie, 1975; Jones, 1986; Butt and Royle, 1990).

In establishing some weather-based predictive and forecasting systems the duration of rainy periods, leaf wetness duration, and temperature have been used (Ryan and Clare, 1975; Rotem et al, 1976; Gillespie and Sutton, 1979; Sutton et al, 1984; Jones, 1986; Royle and Butler, 1986). Models such as those developed to predict wheat diseases caused by Septoria spp. have considered water related variables and temperature. In one empirical model septoria leaf blotch of wheat caused by S. tritici was predicted based on temperature and rainfall data collected over a 20-year period (Shaner and Finney, 1976). A combination of daily rainfall and relative humidity were included in a model to predict the disease caused by S. nodorum on wheat (Tyldesley and Thompson, 1980). However the use of daily rainfall records as such have been criticized primarily because they do not explain the pathway of action of this variable in the disease cycle or pathogen life cycle, and

secondly because no standard meteorological stations record information about duration or intensity of precipitation (Coakley, 1988; Royle and Butler, 1986). Other fundamental models have established a positive correlation between the increase of moisture after inoculation and the increase of postinfection temperature with the disease severity of septoria blotch of wheat (Hess and Shaner, 1987). In onion crops, the implementation of a model to predict the daily incidence of inoculum and intensity of infection by Botrytis squamosa, required monitoring of air temperature, duration of wetness, and relative humidity (Sutton et al, 1986).

An improved regression model to predict coffee rust has been suggested by Kushalappa et al (1983, 1984), which reduces the number of independent variables and the repetition of the variables performing similar biological functions. This was achieved by transforming meteorological variables to monocyclic process equivalents for environment, and by calculating survival ratio for the monocyclic process of the pathogen based on paths of biological action. In these models the relationship among component processes is quantitative and for each process the coincidence of various environmental factors influencing pathogen growth is considered. These features make these models more reliable over time and for different locations than the empirical ones.

DISEASE MANAGEMENT. Different techniques such as cultural practices, seed certification, seed treatments by chemical or physical means, and chemical control by fungicide applications have been used to control the late blight of celery (Anonymous, 1966; Simms et al, 1977; Dixon, 1978; Sherf and Macnab, 1986). To reduce initial inoculum of S. apiicola, it is recommended that celery seeds be stored for 3 years after harvest in cool and dry conditions; to treat seeds with a suspension of Thiram; and to fumigate seedbeds (Maude, 1970; Simms et al, 1977; Dixon, 1978; Strandberg, 1982).

Chemical control is widely used to manage septoria blight. Protective fungicides are especially important in both seedbeds and in the field (Maude, 1970). Many fungicides provide good control of the disease. Benomyl, a systemic fungicide provided good control, however, its usage has been restricted since the pathogen has developed a resistance to its use (Paulus et al, 1970; Ryan and Kavanah, 1971; Lacy, 1973; Wicks, 1989). Organotin compounds gave significantly good disease control, even when they were applied with an interval of 28 days after the blight was quite severe and no phytotoxic symptoms were observed (Ryan and Kavanah, 1971; Ryan et al, 1972). Zineb gave significantly poorer disease control as compared to copper fungicides (Sheridan, 1967; Ryan and Kavanah, 1971). In Australia, the most effective control was given by

anilazine, and chlorothalonil (Wicks, 1989). Chlorothalonil is recommended and widely used in Quebec (CPVQ, 1987).

Although it has been recommended that better control can be obtained by following a calendar pattern of fungicide sprays starting early in the cropping season, this rule can not be generalized because disease severity is weather dependant and is in its turn governed by local environmental conditions (Sheridan, 1967; Ryan et al, 1972). In California several fungicides provided good control when applied at 14 day intervals, however, when plants became infected at an early growth stage 7 day intervals were only partially successful (Paulus et al, 1970). In Quebec it is recommended that fungicides be applied at 7-12 day intervals after transplanting (CPVQ, 1987). Also as many as fifteen applications over a period of 11 weeks have been recommended (Darby, 1959). Whatever the methodology used to apply fungicides concern has been expressed for the need to reduce the hazard to the environment through a rational use of pesticides. The development of forecast systems is a valuable tool for such an optimization (Fry, 1982).

There is no specific forecast system to time fungicide application in plant disease management programs. Many of the proposals suggest disease control in advance according to the possible disease changes within the space of the latent period of the disease cycle (Butt and Royle, 1990). A disease forecast system to control alternaria leaf blight on

carrot is based on disease severity and conditions favourable for infection (Gillespie and Sutton, 1979). Another predictive system employs a predetermined threshold of cumulative disease severity units to initiate a spray fungicide program to manage botrytis leaf blight of onion (Sutton et al, 1986). The critical disease level to time fungicide application to control botrytis leaf blight of onion was established based on the average number of lesions per plant. It was suggested that the first application be made when an average of one lesion per ten leaves was observed (Shoemaker and Lorbeer, 1977).

Forecast systems have been developed to help farmers to optimize disease control alternatives through a well implemented management program that includes a rational use of fungicides (Royle and Shaw, 1988). Forecast systems for many diseases have been developed and efforts made to incorporate these within disease management programs. BLITECAST was developed to forecast potato late blight and to time fungicide sprays. The application of fungicides and the number of applications depend on the cumulative index of severity values calculated according to periods of high relative humidity and temperature (Krause and Massie, 1975). To time the initial fungicide application against Botrytis squamosa on onion a forecast system called BOTCAST was developed in Canada. The system considers a cumulative threshold of daily index of severity values and reduces the

number of fungicide applications (Sutton et al, 1986). There is no system developed yet to forecast celery late blight. There is an economical need to control the disease. The efficiency in fungicide application and a lower risk to human health and the environment are important factors.

STUDY I. DEVELOPMENT OF MODELS TO PREDICT SPORULATION BY *Septoria apiicola* IN CELERY AS FUNCTIONS OF TEMPERATURE AND OF RELATIVE HUMIDITY

INTRODUCTION

Septoria blight of celery can be very serious in years when there is more frequent rain, especially if associated with high initial inoculum. Further increase of the disease depends on the production and effectiveness of secondary inoculum.

A fundamental study is imperative to understand the factors that influence the production, dissemination and infection efficiency of spores (Fry, 1982; Fitt et al, 1989; Campbell and Madden, 1990). Among other factors, weather conditions play an important role in the sporulation process. Temperature and relative humidity have been the subject of study in various pathosystems. At optimal temperatures, moisture is critical for formation, release, and dispersion of spores in pycnidial fungi (Colhoun, 1973; Fry, 1982; Fitt et al, 1989).

Spore production, as affected by weather factors, can be described and predicted in time and space by employing mathematical models. These models can be later used in disease forecasting systems (Kranz, 1974). Statistical

methods such as multiple regression analysis have been employed to develop models to describe sporulation of Plasmopara viticola, Botrytis squamosa, and Septoria tritici (Alderman et al, 1985; Hess and Shaner, 1987; Lalancette et al, 1988). Not much information is available on quantification of spore production of S. apiicola as influenced by weather factors (Benedict, 1973; Louis and Cooke, 1985). The objective of this study was to develop models to predict the amount of spores produced by S. apiicola as a function of temperature and relative humidity.

MATERIALS AND METHODS

Preparation of plants. The experiments were carried out in the Phytotron facility of the Department of Biology, McGill University, Montreal, Quebec, Canada. Celery cultivar Florida 683 was used in the experiments. The transplants were produced in speedling cells 080A filled with organic soil. One coated celery seed per cell was placed on the soil surface and then lightly covered with a layer of fine sand. The tray was placed on a bench in a greenhouse adjusted to 20 and 18 C day and night temperatures, respectively, and 18/6 hr light/dark cycles. Six weeks after seeding, the seedlings at the second leaf stage were transplanted to plastic pots, 12 cm internal

diameter, containing organic soil. Fertilizer solution (2 g/6l of 15-15-18) was applied twice weekly; a calcium chloride solution (8 g/l of $CaCl_2$) was applied weekly, to prevent black heart. Plants were misted at hourly intervals (10 sec/hr) until they were inoculated.

Preparation of inoculum. Conidia of S. apiicola were isolated from artificially infected plants growing in growth chambers maintained at 20 C at the Phytotron facility of Macdonald Campus. Lesions which developed on the leaves of these plants were cut out and placed for 24 hr inside a Petri dish containing a moist filter paper. The exuding cirri from the pycnidia were suspended in another Petri dish containing 2 ml sterile distilled water (Hewett, 1968). Five drops of this spore suspension (120 µl each) were transferred to each Petri dish containing 15 ml of sterilized Celery Agar (CA). The CA was prepared by mixing a strained decoction of 100 g shredded celery leaves, 15 g Difco agar, and 4 g Difco potato dextrose broth in 1 l distilled water (MacMillan, 1942; Tuite, 1969; Mathieu, personal communication). The plates were incubated for two weeks in an incubator under 20 C and 12/12 hr day/light cycles. Only two week old cultures were used for inoculation. A fresh source of inoculum was maintained by inoculating celery plants, cultivar Florida 683, at three week intervals.

Inoculation. Inoculum was prepared by flooding two week old cultures on CA media with a solution of 0.01 % Tween 80 (v/v) in sterile distilled water and rubbing the colony surface gently with a glass spreader to disperse the spores. The bulk spore suspension was filtered through two layers of sterile muslin cloth to remove mycelial and pycnidial fragments and the suspension was further diluted with sterile distilled water to obtain a concentration of 20,000 spores/ml. The spore concentration was determined based on 10 counts using a haemocytometer (Tuite, 1969). A germination test was done on PDA before each inoculation.

At the five leaf stage plants were inoculated by spraying a spore suspension of S. apiicola at a concentration of 20,000 spores/ml. The suspension was sprayed with an atomizer attached to a pressure pump (34.5 kPa). After inoculation, the plants were covered with clear plastic bags to create a water saturated atmosphere and kept in a greenhouse adjusted to 18 and 20 C day-night temperatures and 18/6 hr light/dark regimes. After 72 hr the plastic bags were removed.

After a period of 12 days when lesions were formed, plants were transferred to a growth chamber adjusted to 20 C and 18/6 hr light and dark cycles and 65 %RH for a period of 24 hr to reduce the variation in greenhouse temperature and relative humidity. Then the plants were subjected to two different treatments of different levels of relative

humidity or temperatures for various lengths of time.

Experimental design and treatments. The experiments were arranged in a split plot design where relative humidity and temperature were the main plots and durations were the subplots, with two replicates and three plants as sampling units. The whole experiment was conducted twice. A total of 30 combinations of relative humidity and duration were tested. The test consisted of five levels of relative humidity 65, 88, 92, 96% and wet as well as six durations 6, 12, 24, 48, 72 and 96 hr. Four growth chambers were used for the experiment at the same time. They were adjusted to 65, 88, 92, and 96% RH, respectively, at 20 C constant temperature and 18/6 hr light and dark cycles. The photon flux density inside each chamber was 300 $\mu E.m^{-2}.sec^{-1}$. Light was supplied by fluorescent and incandescent lamps. The wet condition was provided by spraying the plants with water and covering them with clear plastic bags. These plants were placed in one of the four growth chambers chosen at random.

A total of 24 combinations of levels and durations of temperature were tested. The four levels of temperatures were 15, 20, 25 and 28 C and the durations were 6, 12, 24, 48, 72, and 96 hr. Four growth chambers maintained at four different temperatures at the same time and adjusted to 18/6 hr light/dark cycles were used for this experiment. The photon flux density inside each chamber was 300 $\mu E.m^{-2}.sec^{-1}$.

Light was supplied by fluorescent and incandescent lamps. The temperature inside the plastic bag was 0.5 to 1.0 C higher than the adjusted temperature of the growth chamber, when the lights were on.

Quantification of sporulation. Following relative humidity and temperature treatment for various durations, three plants were removed. From each plant five lesions were cut out at random in the third and fourth leaves from the bottom using a cork borer. The lesions were placed in test tubes containing 5 ml of 1% formaldehyde solution and 0.01% Tween 80 and then agitated for 5 minutes. Formaldehyde was used to prevent the spores from germinating and Tween 80 to dislodge and disperse spores. The number of spores in the suspension was counted using a haemocytometer (twenty chambers of 0.1 mm^3 each). Sporulation was calculated as the number of spores produced per mm^2 of lesion area:

$$S = SML * TVS/LA \qquad (1)$$

where S is the number of spores produced per mm^2 of lesion area; SML is the number of spores per ml of suspension; TVS is the total volume of suspension; LA is the total lesion area in mm^2 for five lesions.

After the spores were harvested the leaf segments were bleached in Farmer's fixing solution (2 vol absolute ethanol

and 1 vol glacial acetic acid) for 24 hr. The bleached leaf segments were placed between two microscope slides and the diameter was measured using a dissecting stereomicroscope with dark field attachment and fitted with a micrometer.

Data analysis. The data on the number of spores were transformed to square roots (Gomez and Gomez, 1984). An analysis of variance for a split plot design was carried out using the GLM procedure (SAS, 1987). Provided that the errors were not significantly different (P=0.01) they were pooled and an error term was used in further analysis. Based on significance (P=0.01) of interaction, treatments were partitioned into orthogonal polynomial contrasts using the GLM procedure (SAS, 1987). A multiple regression equation based on means for treatment was performed using the GLM procedure (SAS, 1987). To select the variables to be included in the model an F-test was performed using the error mean square obtained when all the possible combinations were considered in the model. The models were selected based on R^2 and significance (P=0.01) of the independent variables, and partial regression coefficients.

RESULTS

Effect of level and duration of relative humidity on

spore production. Spores were found at all combinations of levels and durations of relative humidity tested. However, the highest mean number of spores was observed after 48 hr at wet conditions. This amount represents more than double the number of spores produced at 96% RH (Fig 1.1). Both, the effect of relative humidity and the interaction between levels and durations of relative humidity on spore production, were significant at P=0.01 (Appendix 1.1).

The effect of duration of relative humidity on spore production was linear at 65% RH, whereas at 96% RH and wet the effect was quadratic. At 88 and 92% RH the effects were cubic (Appendix 1.2). Specific models for each level of relative humidity based on orthogonal polynomials were not included because the objective of this study was to develop a model to predict sporulation from RH. The following equation gave the best fit (Fig. 1.2):

$$\sqrt{S} = 165.29362 + 0.57882*RH^2 + 0.02799*RH^3 + 0.97790*DW - 0.00254*RH*DW^2 + 0.00001*RH*DW^3 - 0.00010*RH^3*DW^2 \quad (2)$$

where S is the number of spores per square millimetre of lesion area, RH is relative humidity and DW is duration of exposure; the $R^2 = 0.86$ and CV = 12.76 (Appendix 1.3).

Effect of temperature and duration of wetness on spore production. Spores were produced under all combinations

Fig. 1.1. Effect of level and duration of relative humidity (RH) on the number of spores of S. apiicola produced per mm^2 of lesion area (LA) on celery leaves cv. Florida 683. Infected plants were placed in growth chambers maintained at constant temperature (20 C). Each point is an average of two replicates. Each replicate is an average of fifteen lesions sampled from 3 plants.

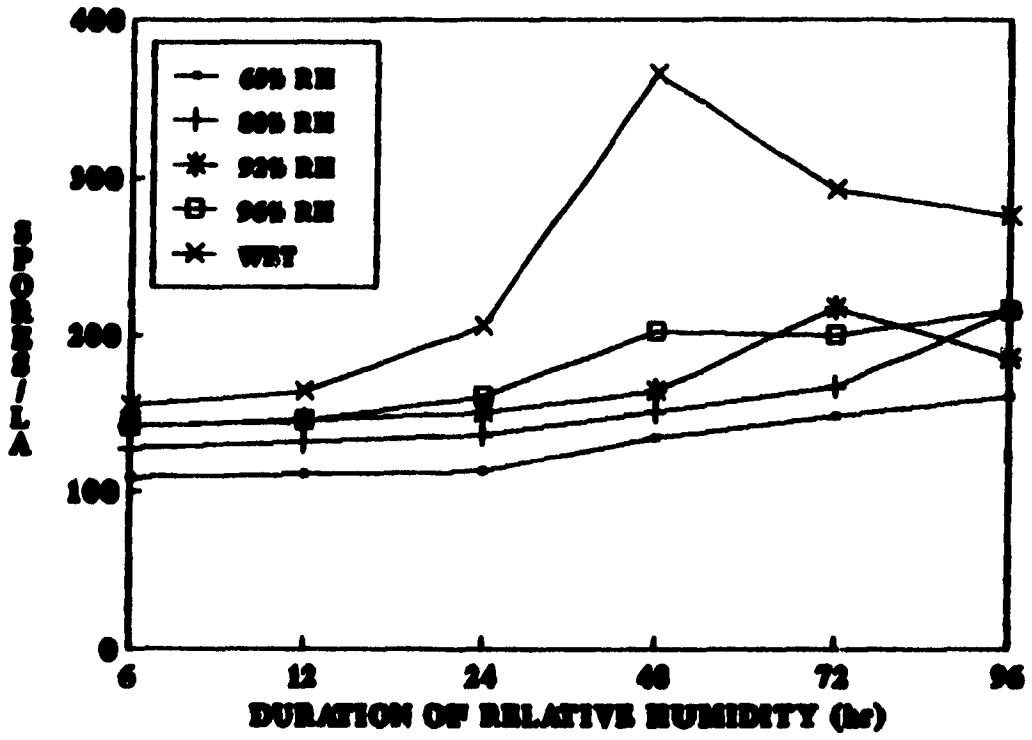
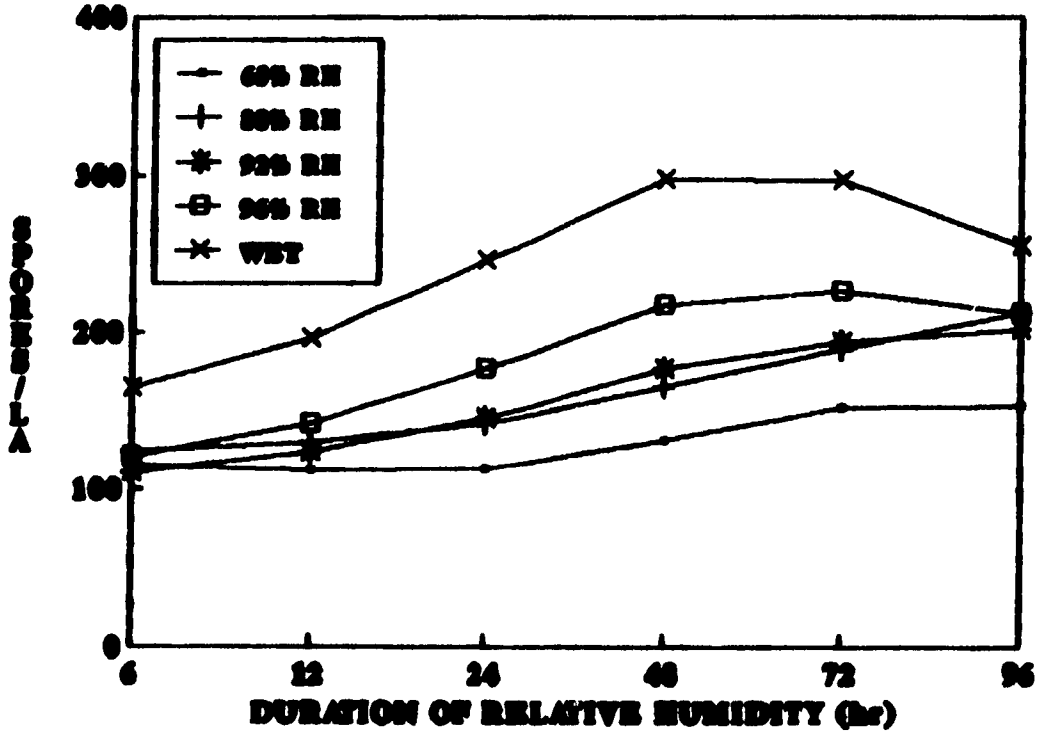

400
300
200
100
0
65% RH
80% RH
92% RH
96% RH
WET
6
12
24
48
72
96
DURATION OF RELATIVE HUMIDITY (hr)

Fig. 1.2. Number of spores of S. apiicola produced per mm^2 of lesion area (LA) on celery leaves cv. Florida 683 predicted from level and duration of relative humidity (RH). Predicted values were calculated using Eq. 2.


400
300
200
100
0
SPORES/LA
60% RH
80% RH
92% RH
96% RH
WET
6
12
24
48
72
96
DURATION OF RELATIVE HUMIDITY (hr)

of temperature and duration of wetness tested here. The largest number of spores was observed after 48 hr of exposure at 20 C. The lowest amount was found at 28 C at 48 hr. The largest amount of spores at 25 C was found after 72 hr of exposure (Fig 1.3). The effect of levels of temperature and duration of wetness as well as the interaction between them on spore production were significant at P=0.01 (Appendix 1.4). The orthogonal polynomial contrasts showed that the effect of duration of wetness on spore production was quadratic at 15 C and cubic at 20, 25, and 28 C (Appendix 1.5). Individual equations based on polynomial contrasts were not considered here but a model (Eq. 3) considering both levels of temperature and durations of wetness is formulated (Fig. 1.4):

$$\sqrt{S} = 262.68484 - 8.25918*T - 1.24981*T^2 - 0.02427*DW^2 - 0.07762*T*DW + 0.00066*T^2*DW^2 + 0.00006*T^3*DW^2 \quad (3)$$

where S is the number of spores produced per square millimetre of lesion area, T is temperature, and DW is duration of wetness. Equation 3 had an $R^2 = 0.80$ and C.V.= 7.43 (Appendix 1.6).

Fig. 1.3. Effect of temperature and duration of wetness on the number of spores of S. apiicola produced per mm^2 of lesion area (LA) on celery leaves cv. Florida 683. Infected plants covered with plastic bags were placed in growth chambers maintained at different temperatures. Each point is an average of two replicates. Each replicate is an average of fifteen lesions sampled from 3 plants.

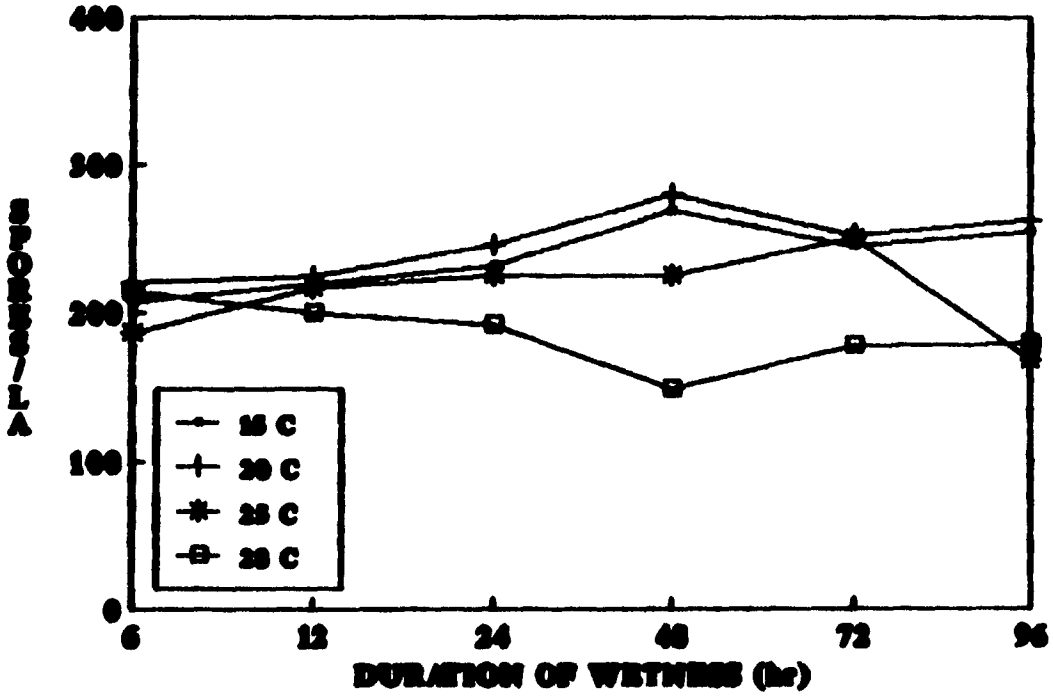
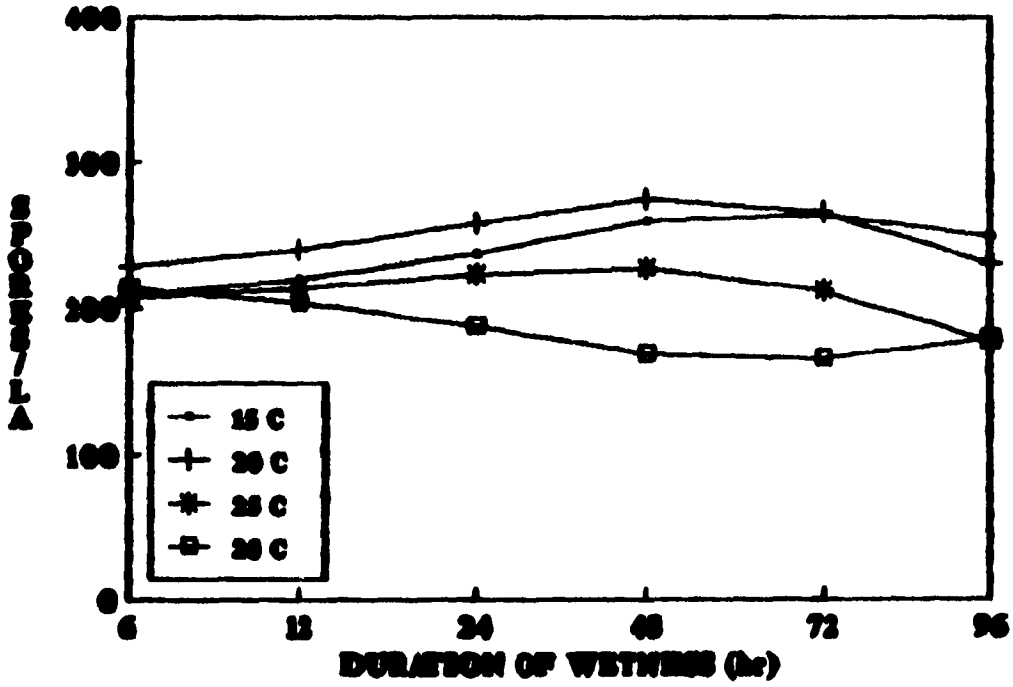

400
300
200
100
0
STRESS/LA
15 C
20 C
25 C
30 C
6
12
24
48
72
96
DURATION OF WETNESS (hr)

Fig. 1.4. Number of spores of S. apiicola produced per mm^2 of lesion area (LA) on celery leaves cv. Florida 683 predicted from level of temperature and duration of wetness. Predicted values were calculated by Equation 3.


400
300
200
100
0
SPORES/LA
15 C
20 C
25 C
30 C
6
12
24
48
72
96
DURATION OF WETNESS (hr)

DISCUSSION

Sporulation by S. apiicola as affected by relative humidity and temperature has not been previously quantified. The studies reported here explain the importance of wetness on spore production by S. apiicola and the development of septoria blight epidemic. The highest spore production after 48 hr of wetness and temperatures between 15 and 20 C reported here are close to the optimum conditions reported for sporulation of S. tritici (Gough and Lee, 1985). A wetness period of about 48 hours at 15-25 C should be considered very critical for the development of septoria blight of celery because it favours not only spore production but also spore gemination and infection (Berger, 1970; Mathieu personal communication). However, the temperature and wetness duration required for a higher sporulation are within the range of optimal weather requirements for celery production, that is, high moisture and a temperature of 15 to 21 C (Halfacre and Barden, 1979; Anonymous, 1973). In addition, it has been shown that S. apiicola produced spores at all levels of relative humidity and temperature tested here and these environmental conditions are of common occurrence throughout the celery growing season. For these reasons, the use of temperature and relative humidity to predict spore production and its further use in forecasting is not of much significance

(Strandberg, 1977). However, in Quebec temperatures less than 15 C and more than 28 C can be found for short periods on certain days. Therefore, a broader range of temperature and lower levels of relative humidity should be tested to find the lowest and highest levels under which spores are not produced in order to determine the conditions that could limit the epidemic development.

The length of wetness periods plays an important role in disease development. In this study a decrease in the amount of spores was observed at wet conditions after 48 hours. This is because under persistent wetness the cirri are dissolved and the spores will be suspended in a layer of free water and then washed out from the leaf surface. In the field it is responsible for a rapid spread of celery late blight (Berger, 1970).

However, the duration of wetness in the interval between sporulation and subsequent infection could affect the epidemic development of septoria blight of celery by influencing spore viability. A change of spore viability was observed in S. tritici. During the period that spores were protected by the gelatinous matrix in cirri, their viability was unchanged for a period of 15 days at different levels of relative humidity. If the conditions of relative humidity higher than 60% are persistent after sporulation the spore viability drops significantly to a level of 5% in 15 days (Gough and Lee, 1985). There is no information available on

the spore viability of S. apiicola and so studies should be conducted to identify the factors influencing spore viability and spore survival.

In general, to quantify the effect of weather factors on sporulation of foliar pathogens, lesions have been exposed to various treatments (Strandberg, 1977; Gough and Lee, 1985; Lalancette et al, 1988). However this procedure is neither appropriate nor accurate to septoria blight of celery since spores were found as soon as the lesions were visible and pycnidia were observed both in the necrotic area and in the green tissue around the lesion. The presence of pycnidia in symptomless tissue in celery has been previously reported (Gabrielson and Grogan, 1964). The production of spores under low level of relative humidity could be explained by the close contact between cells of the host and pycnidia that allows water absorption by the fungus (Ingold, 1978). Thus the effect of environment must be studied well before the appearence of lesions.

There is a lack of information about the effect of relative humidity and temperature during the postinoculation period which in turn may influence sporulation. Studies are also required on the number of crops of spores produced by pycnidia and on the influence of aging pycnidia on spore production by S. apiicola.

The models presented here for sporulation as functions of relative humidity and of temperature could be used in

forecasting celery blight but their role may not be very significant under Quebec celery growing conditions.

STUDY II. DEVELOPMENT OF A MODEL TO PREDICT LATENT PERIOD FOR *S. apiicola* IN CELERY AS A FUNCTION OF TEMPERATURE

INTRODUCTION

Latent period is a period of time from inoculation until the new lesions produced become infectious (Campbell and Madden, 1990). After each latent period the pathogen has a new generation of spores and a new source of inoculum becomes available. Latent period is a measure of the frequency at which a new generation of spores are produced on a susceptible host, thus determining the number of generations possible in a cropping season. The length of latent period varies depending on pathogen, host, and environment. Thus it must be considered in the analysis of disease development and in forecasting models (Kranz, 1978).

Environmental factors such as temperature and wetness are important factors in determining the length of latent period (Shearer and Zadoks, 1972). The effect of temperature on the length of latent period is well documented. Generally, latent period is longer at unfavourable temperatures for pathogen growth (Colhoun, 1973).

The length of latent period of septoria blight of celery has been related to environmental factors (Berger,

1970; Sherf and Macnab, 1986) but no model has been developed, to date, to predict latent period based on temperature. Latent period, in the past, has been used to develop models to predict disease in the field. In a survival ratio model developed for coffee rust a fixed latent period was used to relate the factors influencing infection to the amount of disease observed in the field after one latent period (Kushalappa and Eskes, 1989). However, if the latent period is significantly variable within a cropping season a variable latent period predicted based on temperature must be used to develop a disease prediction model.

The objective of this research was to develop a model to predict latent period as a function of temperature under field conditions, so that it could be employed in developing and validating models to predict septoria blight in the field.

MATERIALS AND METHODS

Fifteen plants were produced (see Study I) at weekly intervals in growth chambers adjusted to 20/18 C day/night temperatures, and 18/6 hr light/dark cycles, respectively. The photon flux density inside each chamber was 300 uE.m^{-2}.sec^{-1}. Light was supplied by fluorescent and incandescent

lamps. In addition, 30 plants were produced in the greenhouse of the Plant Science Department to plant in border rows, in order to simulate the microclimatic conditions.

The plants produced in growth chambers were inoculated at the fifth leaf stage. Two leaves, the second and the third from the bottom of each plant, were tagged and inoculated by spraying them with a spore suspension of the fungus (Septoria apiicola) containing 20,000 spores /ml (See Study I). The suspension was sprayed onto the plants using an atomizer attached to a pressure pump (34.5 kPa).

After inoculation the plants were covered with clear plastic bags to create a water-saturated atmosphere and incubated for 72 hr in an incubator adjusted to 20 C and 18/6 hr light/dark cycles.

Field work. The inoculated plants were transplanted to the field at the Agriculture Canada Research Station, Ste. Clotilde. The well developed root system in the potted plants held the soil mix intact while transplanting.

Fifteen inoculated plants were planted at weekly intervals for nine weeks, during June, July and August 1989. The spacing was 20 cm within the row and 90 cm between rows. Fifteen non-inoculated plants were transplanted on either side of the inoculated rows of plants to provide favourable microclimatic conditions. Fertilizer was applied by

broadcasting at a rate of 110, 40 and 220 kg/ha of N, P, and K, respectively, in a single application before transplanting. In order to correct for a boron deficiency, Solubor (21%B) was applied at a rate of 1.5 kg/ha one month after transplanting. Weed control was performed by hand twice monthly. The plants were overhead-irrigated twice weekly at a rate of 24 mm per application.

The air temperature was monitored using a CR 10 micrologger (model 207, Campbell Scientific Canada Corp.) positioned at 1 m height above the ground. From hourly temperature records, the average of maximum and minimum daily temperatures were obtained.

Data collection. The number of lesions with pycnidia, on each of the two inoculated leaves per plant, was counted three times per week. The readings were taken from the day the lesions with pycnidia were observed for the first time until the day that two consecutive readings resulted in an equal or lesser number of lesions (Parlevliet, 1975).

Data analysis. From data on number of lesions/leaf, for 15 plants, the Latent Period Beginning (LPB), the Latent Period Ending (LPE) and the Latent Period 50% (LP50%) were determined for each plant and for each of the nine plantings. The LPB was calculated as the period in days from inoculation until about 5% of the maximum number of lesions

appeared. The LPE was calculated as the period in days from inoculation until about 95% of the maximum number of lesions appeared. The LP50% was calculated as the period in days from inoculation until about 50% of the maximum number of lesions appeared. The data for all nine plantings for LPB and LPE were pooled so that a prediction equation could be developed for a range of maximum and minimum temperatures registered in the experiment. The independent variables, mean maximum and mean minimum temperatures, were calculated for latent period durations of each planting, and were regressed against the dependent variable latent period. Thus, the latent period may be explained as a function of mean minimum and mean maximum temperatures:

$$LPB = f(MTXB, MTMB) \quad (4)$$

$$LPE = f(MTXE, MTME) \quad (5)$$

where MTXB and MTMB are, respectively, the mean maximum and the mean minimum temperatures during LPB; MTXE and MTME are the mean maximum and the mean minimum temperatures during LPE, respectively.

Regression analysis were performed using the GLM procedure of Statistical Analysis System (SAS, 1987).

RESULTS

Latent period beginning. There is no general trend to explain the effect of temperature on latent period. For each inoculation not all lesions appeared on the first day. Lesions varied in the rate of their appearance among plantings. Table 2.1 shows the mean latent period beginning (MLPB) calculated based on the initial number of observed lesions on fifteen plants for each planting. The MLPB varied from 10 to 14 days for the nine plantings, with an overall mean of 11.7 days. In the first planting 74% of the total number of lesions was registered on the first reading day whereas only 11% of lesions were registered on the first reading day for the seventh planting. For all nine plantings the mean number of lesions registered on the first day of reading was 30% of the total.

During LPB, the mean maximum temperature for LPB (MTXB) varied from 21 to 27 C, whereas the mean minimum temperature (MTMB) varied from 12 to 18 C (Table 2.2).

Attempts were made to develop a polynomial multiple regression model to predict LPB as a function of MTXB and MTMB. However, more than two terms (MTMX and MTMB) in the model produced larger regression coefficients which were very difficult to understand from the biological point of view. Therefore, a linear regression model (Eq 6) is presented here:

Table 2.1. Mean latent period beginning, percentage of maximum number of lesions formed on LPB, LP50% and mean latent period ending for septoria blight of celery at different inoculation dates in the year 1989.

Inoculation Dates Day/Month	MLPB	% Lesions on LPB	LP50%	MLPE
30/6	14	74.31	14	22
8/7	13	39.27	16	20
14/7	12	20.42	14	19
21/7	13	14.21	17	20
28/7	11	16.07	14	18
4/8	10	15.16	14	18
11/8	11	10.62	14	18
18/8	10	61.92	10	14
25/8	12	20.66	14	18
MEAN	11.78	30.29	14.11	18.55

MLPB Mean latent period beginning in days
LP50% Latent period 50% in days
MLPE Mean latent period ending in days

Table 2.2. Mean maximum and mean minimum temperatures recorded during latent period beginning and latent period ending for different inoculation dates in the year 1989. Temperatures included an initial 72 hr moist period at constant 20 C and field temperatures derived from hourly temperature recorded in the canopy of celery cv. Florida 683 inoculated with *S. apiicola*.

Inoculation Dates	Average Mean Temperature			
	Latent Period Beginning		Latent Period Ending	
Day/Month	MTXB	MTMB	MTXE	MTME
30/6	26.10	14.48	27.22	15.40
8/7	24.87	14.87	26.80	15.98
14/7	27.08	17.53	27.01	15.55
21/7	26.15	15.70	26.10	14.87
28/7	24.86	16.44	22.61	13.37
4/8	23.58	14.27	24.37	13.16
11/8	24.04	13.87	23.55	12.16
18/8	21.59	12.38	22.38	12.36
25/8	22.25	12.40	23.83	13.12

MTXB is the average of the mean maximum temperature registered during Latent Period Beginning (LPB) for each inoculation.
MTMB is the average of the mean minimum temperature registered during Latent Period Beginning (LPB) for each inoculation.
MTXE is the average of the mean maximum temperature registered during Latent Period Ending (LPE) for each inoculation.
MTME is the average of the mean minimun temperature registered during Latent Period Ending (LPE) for each inoculation.

$$LPB = -9.4115 + 1.7000*MTXB - 1.3988*MTMB \quad (6)$$

where, LPB is the latent period beginning, MTXB is the mean maximum temperature during LPB and MTMB is the mean minimum temperature during LPB. The model had an $R^2=0.57$ and C.V.=9.12% (Appendix 2.1). Predicted values calculated by Equation 6 are presented in Fig. 2.1.

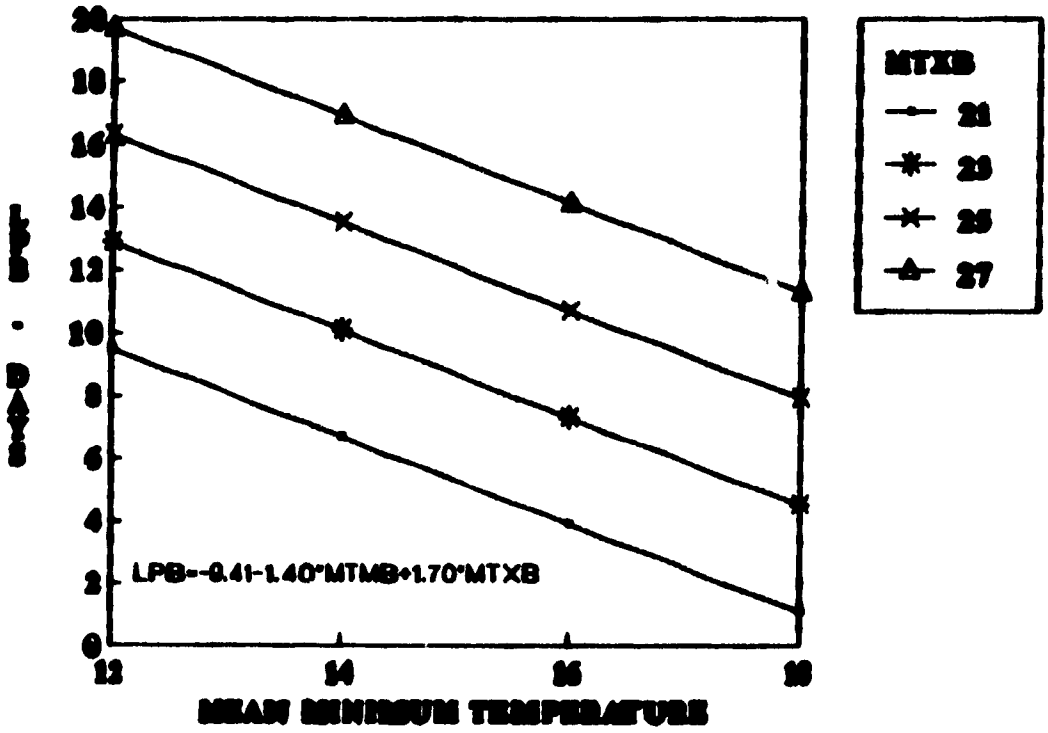
Latent period ending. The mean Latent Period Ending (MLPE) for each planting calculated based on the final number of lesions observed on fifteen plants for each planting varied from 14 to 22 days with an overall mean of 18.55 days (Table 2.1). The shortest LPE corresponded to lowest MTXE whereas the longest LPE to the highest MTXE.

The mean maximum temperature (MTXE) registered for this period varied from 22 to 27 C; and the mean minimum temperature (MTME) varied from 12 to 16 C (Table 2.2).

In order to develop a polynomial multiple regression model to predict LPE as a function of temperature it was found that more than two independent variables (MTXE and MTME) in the equation resulted in larger regression coefficients without biological explanation. For this reason a simple regression model (Eq 7) was developed:

$$LPE = -10.6315 + 1.7073*MTXE - 0.9352*MTME \quad (7)$$

Fig. 2.1. Latent period beginning (LPB) in days predicted from mean minimum and mean maximum temperatures. Predicted values were calculated by Equation 6.


LPB - DAYS
20
18
16
14
12
10
8
6
4
2
0
12
14
16
18
LPB=-8.41-1.40*MTMB+1.70*MTXB
MEAN MINIMUM TEMPERATURE
MTXB
21
23
25
27

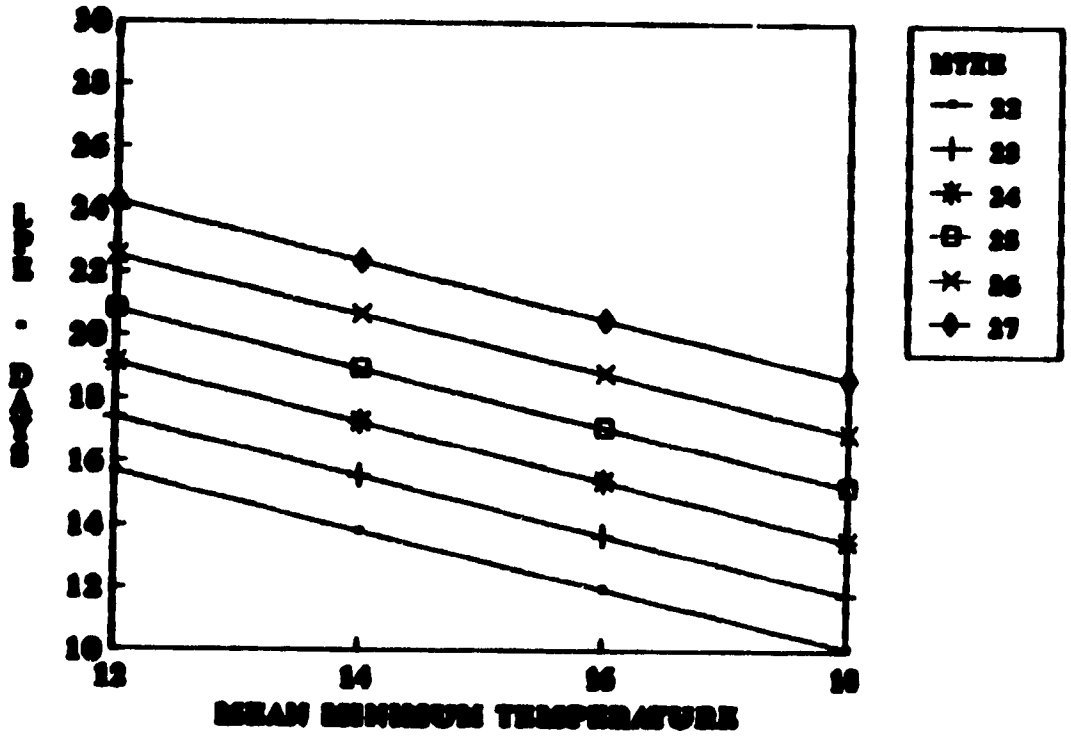
where LPE is the latent period ending, MTXE is the mean maximum temperature during LPE and MTME is the mean minimum temperature during LPE (Appendix 2.2). The model had an R^2 = 0.55 and C.V. = 8.17%. In Fig. 2.2 are represented the predicted values calculated by Equation 7.

Latent period 50%. The mean latent period 50% varied from 10 to 14 days for the nine plantings, with an overall mean of 14 days. The LP50% was closer to the LPB than to the LPE, explaining that 50% of the lesions were formed until the day 14 after inoculation (Table 2.1).

DISCUSSION

The models developed here to predict LPB and LPE included the whole range of temperatures that prevailed during the celery cropping season of 1989. The mean maximum and mean minimum temperatures registered and employed to develop the models to predict LPB and LPE represented a real situation in the field with the exception of the additional exposure of a 72 hr-period of wetness at 20 C immediately following inoculation. In addition, the spore concentration was the same at different inoculations. These standardizations helped to maintain the coefficient of variation at a minimum and to account for most of the

Fig. 2.2. Latent period ending (LPE) in days predicted from mean minimum and mean maximum temperatures. Predicted values were calculated by Equation 7.


28
26
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MEAN MINIMUM TEMPERATURE
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26
27

variation in the length of latent period. Overall, LPB and LPE were longer at higher mean maximum temperatures and shorter at higher mean minimum temperatures. These trends are similar to the results reported by Berger (1970) who found that the length of latent period of septoria blight of celery was longer at higher temperatures under greenhouse conditions. However, not only temperature but the interaction between temperature and leaf wetness after inoculation was a major factor used to establish the latent period of S. nodorum in wheat. An increase of both temperature and leaf wetness duration produced a decrease in latent period (Shearer and Zadoks, 1972, 1974). The same trend was observed with S. tritici in wheat. The latent period decreased as increasing temperature, moisture and cultivar susceptibility (Hess and Shaner, 1987).

The effect of temperature on latent period is a complex phenomenon since it affects the development of the host, the pathogen, and the disease. Lower temperatures are associated with greater accumulation of nutrients in plant tissues which could be used by the fungus favoring the colonization process and symptom expression (Castor et al, 1977; Dahlberg and Van Etten, 1982). At high temperature it is possible to find a faster exhaustion of nutrients from the host and consequently a reduction in the processes involved in fungal life cycle. However, temperature is a relative factor that varies asother weatherconditions vary (Cohenand Rotem,1984.)

The LPB as described in this study is a good measure for latent period to be used in calculating the onset of disease under field conditions and for application in disease forecasting. When a fixed LPB is required, 12 days could be used in Quebec. This LPB is close to a mean latent period 50% of 14 days.

The difference in disease between latent period beginning and latent period ending is the amount of disease developed due to the infection which occurred one latent period earlier. Thus, various factors influencing infection such as inoculum availability and weather conditions could be related to the increase of the disease in order to identify specific factors influencing epidemic development. Such information could be used in developing disease prediction and disease forecast models (Kushalappa and Eskes, 1989).

STUDY III. SIMPLE FORECAST MODELS TO TIME FUNGICIDE APPLICATION IN THE MANAGEMENT OF SEPTORIA BLIGHT OF CELERY

INTRODUCTION

Forecasting is an important component of a plant disease management program. Lately there is a trend toward replacing the conventional fixed-interval fungicide applications with forecasting systems in which fungicides are applied based on action thresholds. The action thresholds are technical guidelines formulated on one or more important parameters that predict disease development. These parameters may be selected employing empirical or fundamental models. The development of a fundamental model requires the establishment of submodels for the sub-processes of the disease epidemic. The sub-processes such as infection, sporulation, and dissemination are influenced by environmental conditions, and their effects can be described by mathematical models. A forecast model may include one or more models for the subprocess. Infection and sporulation models have often been used successfully to time fungicide application to control early blight of celery, botrytis leaf blight of onions, coffee rust, and potato late blight follow this approach (Berger, 1969; Fry, 1982; Kushalappa et al,

1983; Sutton et al, 1986; Arauz and Sutton, 1989; Kushalapa, 1990; Madden and Campbell 1990). To date, no model has been developed to forecast septoria blight on celery in order to time fungicide application.

The objective of this research was to develop a simple forecast model to time fungicide applications in the management of septoria blight on celery.

MATERIALS AND METHODS

This study was carried out at the Agriculture Canada Research Station Ste. Clotilde during 1989 and 1990. Two plots of 300 m^2 each were planted during the first week of June in 1989 and 1990. One plot was always located in a field where celery was grown the previous year. Production of transplants, spacing, fertilization, irrigation, and weed control were performed as indicated before (see Study 11). Six week old seedlings of celery cultivar Florida 683 were hand transplanted each year. The plot where celery was not grown previously was inoculated during the first week of August (about 10 leaf stage) by spraying with a suspension of 20,000 spores/ml of S. apiicola using a 10 liter manual sprayer (Originale Volpi).

Disease severity assessment. In each plot the disease

severity was assessed, from transplanting, at 3-4 day intervals on fifteen plants selected at random. On each plant the expanded leaves were counted from the bottom to the top. The disease severity was assessed on each leaf using modified Horsfall-Barret scores associated with a diagrammatic scale (Horsfall and Cowling, 1978). For the transformation of the scores to proportion of leaf area diseased and to calculate current proportion of leaf area diseased (CUPLAD), cumulative proportion of leaf area diseased (CPLAD) and cumulative proportion of plants diseased (CPPD) the computer program DISPAR (Kushalappa and Carisse, 1990) was used.

From the CUPLAD the disease increase (DI) due to each inoculation or wet period was calculated as:

$$DI = CUPLAD_{LPE} - CUPLAD_{LPB} \qquad (8)$$

where the subscripts LPE and LPB are latent period ending and latent period beginning, respectively. Though the mean LP50% was 14 days (Study II) the range of LPB varied from 11 to 13 days and the LPE from 14 to 17 days, because the PLAD was recorded only at 3-4 day.

Microclimatic data. A datalogger model CR-10 (Campbell Scientific Canada Corp) was installed in the middle of the uninoculated plot to monitor microclimate. Temperature and

relative humidity sensors were placed in a Stevenson house. Data from these were obtained at one minute intervals and recorded as hourly averages.

Two grid-type surface wetness sensors previously calibrated on celery plants were placed in the plant canopy at two different heights, middle and bottom thirds of two plants, and the positions were changed as the plants grew. The duration of leaf wetness was recorded as an average every 15 minutes.

Data analysis. From weather data for 1989 and 1990 the disease severity values for infection (DSV) were calculated based on the mean hourly temperature during wet periods greater than 12 hr using a chart (Mathieu, 1991). The chart is a result of a growth chamber study carried out to predict infection by S. apiicola on celery. In this study the temperature and duration of wetness influencing infection was transformed into disease severity values; 1 being low infection and 4 being high infection. Duration of leaf wetness less than 12 hr were considered not suitable for blight infections. The DSV was zero when a temperature lower than the minimum established in the chart was registered.

The DSV calculated for a given wet period was designated as current DSV (CUDSV) and the DSV for various wet periods over a cropping season accumulated since transplanting were designated as cumulative DSV (CDSV).

Correlation analysis were conducted between CDSV and the disease parameters CPLAD and CPPD recorded one latent period after the wet periods; and between CDSV and CUPLAD. Also a regression equation was developed to predict the DI based on CUDSV. Correlation and regression analysis were performed by the GLM procedure (SAS, 1987).

RESULTS

Disease development. Disease severity was higher in inoculated plots than in uninoculated. In inoculated plots the initial symptoms were observed 75 and 77 days after transplanting in 1989 and 1990, respectively (Fig 3.1, Fig 3.2). The maximum CPLAD reached were 0.31 and 0.40 at 100 and 111 days after transplanting in 1989 and 1990, respectively.

In the uninoculated plots the initial disease symptoms were observed 77 and 79 days after transplanting in 1989 and 1990, respectively (Fig 3.1, Fig 3.2). These disease foci were unevenly distributed as compared to uniform distribution in inoculated plot. The maximum CPLAD reached were 0.107 and 0.284 at 100 and 111 days after transplanting in 1989 and 1990, respectively. For both years a CPLAD of 0.005 was observed approximately 85 days after transplanting. At the same time the CPPD were 0.11 in

Fig. 3.1. Cumulative proportion of leaf area diseased (CPLAD), *Septoria apiicola* on celery, calculated for inoculated and uninoculated plots during 1989. Each point represents the value of fifteen observations taken on plants selected at random.

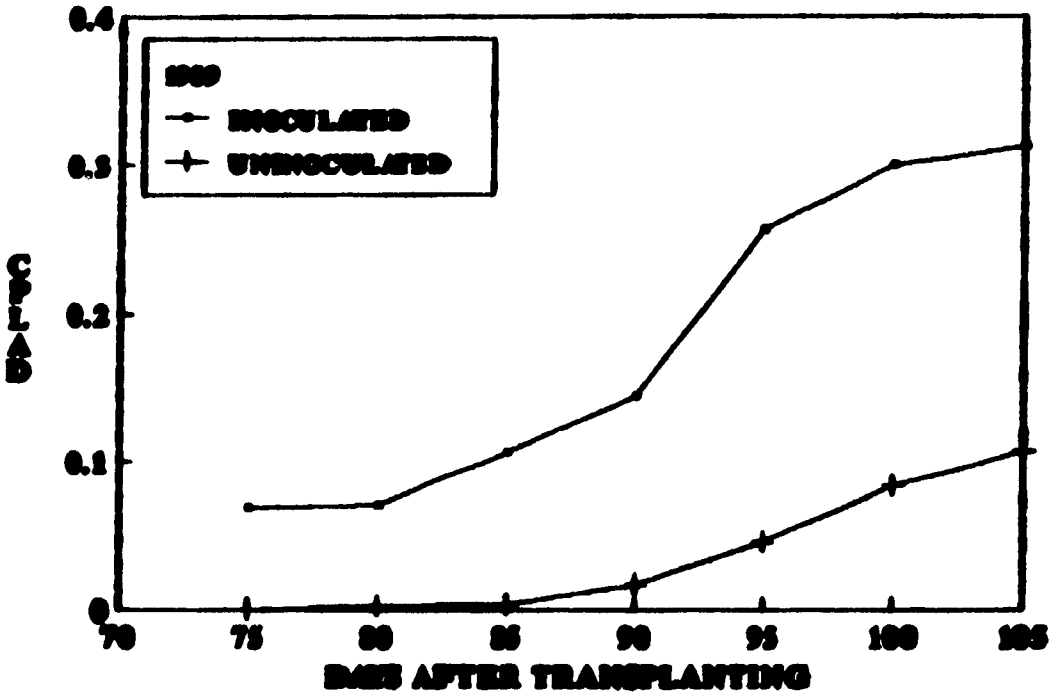
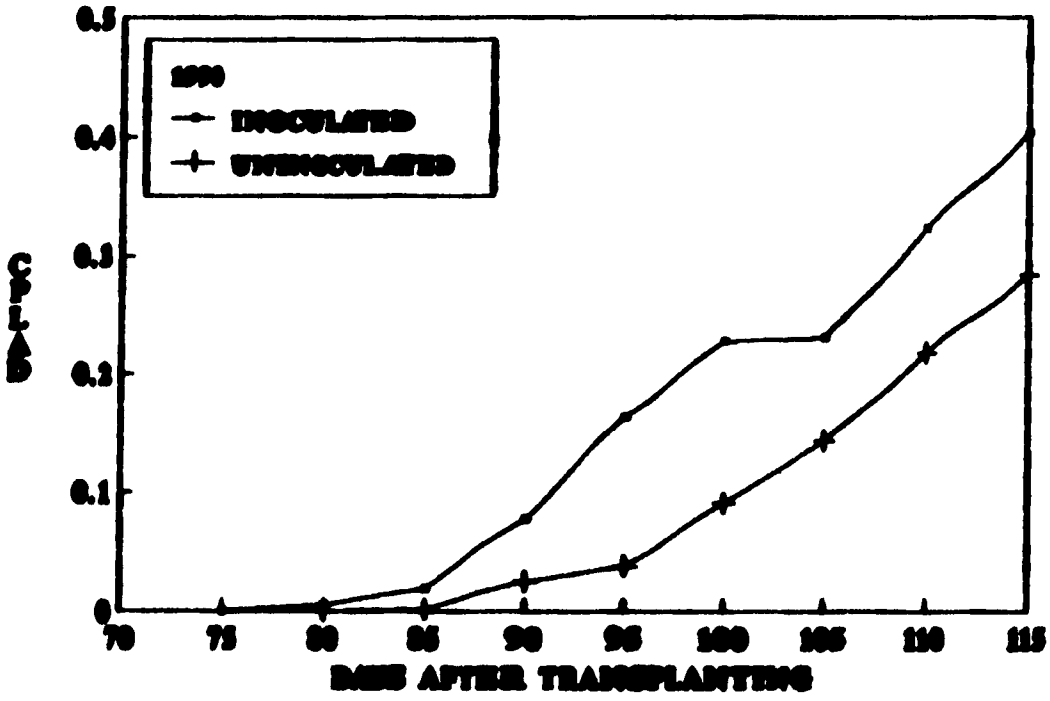

0.4
0.3
0.2
0.1
0
70
75
80
85
90
95
100
105
DAYS AFTER TRANSPLANTING

Fig. 3.2. Cumulative proportion of leaf area diseased (CPLAD), Septoria apiicola on celery, calculated for inoculated and uninoculated plots during 1990. Each point represents the value of fifteen observations taken on plants selected at random.


0.5
0.4
0.3
0.2
0.1
0
70
75
80
85
90
95
100
105
110
115
CFUs
DAYS AFTER TRANSPLANTING

1989 and 0.09 in 1990 (Fig 3.3).

In general younger leaves were less affected by the disease. The first and second leaves from the top did not show any symptom of the disease during both years, whereas the older leaves were heavily infected. No appreciable differences were found in total number of leaves formed per plant between years. The average maximum number of leaves formed per plant was 11.6 for both plots in 1989, whereas it was 14.2 and 13.3 in uninoculated and inoculated plots in 1990, respectively.

Disease severity values. A total of 16 wet periods longer than 12 hr were registered during the cropping season of 1989, whereas 19 wet periods were registered in 1990. In both years the first wet period was registered approximately 30 days after transplanting. The longest wet periods observed were 40 and 118 hr during 1989 and 1990, respectively. During wet periods the range of temperature registered varied from 7 to 27 C and from 2 to 23 C, for 1989 and 1990, respectively (Table 3.1, 3.2).

The current disease severity value (CUDSV) varied from 0 to 3 in 1989 and from 0 to 4 in 1990 (Table 3.1, 3.2).

Fig. 3.3. Cumulative proportion of plants diseased (CPPD), Septoria apiicola on celery, calculated for uninoculated plots during 1989 and 1990. Each point represents the value of fifteen observations taken on plants selected at random.

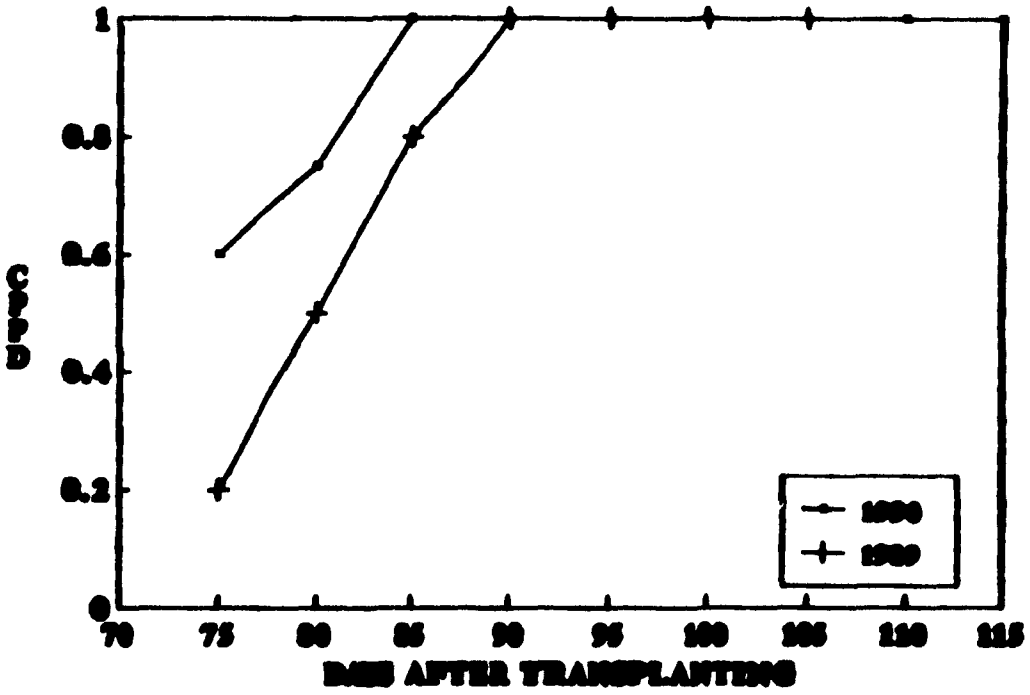

1
0.8
0.6
0.4
0.2
0
70
75
80
85
90
95
100
105
110
115

Table 3.1. Current disease severity values and cumulative disease severity values calculated based on mean temperature and duration of wetness periods during 1989.

Wet Periods		Mean ** Temperature	Severity Values	
Hr	Day of Year		Current	Cumulative
22	179	18.0	1	1
16	182	18.8	1	2
16	185	18.8	1	3
18	205	27.1	3	6
16	207	25.1	3	9
20	208	20.8	3	12
16	209	14.2	1	13
12	210	14.2	1	14
12	219	21.1	2	16
16	221	20.8	2	18
30	224	19.4	2	20
40	227	19.4	2	22
20	232	18.6	1	23
15	236	7.4	0	23
15	239	12.6	1	24
13	241	15.4	1	25

** Mean temperature during wet period calculated from hourly temperature.

Table 3.2. Current disease severity values and cumulative disease severity values calculated based on mean temperature and duration of wetness period during 1990.

Wet Periods		Mean ** Temperature	Severity Values	
Hr	Day of Year		Current	Cumulative
12	187	12.71	1	1
14	189	19.60	1	2
13	194	12.24	1	3
14	196	23.29	2	5
36	197	23.10	3	8
14	202	19.76	1	9
101	203	22.08	4	13
41	211	18.86	2	15
48	217	19.84	2	17
35	221	20.15	3	20
42	224	19.83	2	22
37	227	19.23	2	24
44	230	16.17	1	25
17	234	9.51	1	26
118	237	11.28	1	27
100	246	12.87	1	28
13	259	6.54	0	28
15	261	2.94	0	28
42	263	11.19	1	29

** Mean temperature during wet period calculated from hourly temperature.

Approximately at the time of harvest the cumulative disease severity value (CDSV) reached 25 in 1989 and 29 in 1990. The wet periods were more frequent and some were longer in 1990. However, when the initial disease symptoms were observed in the field the CDSV were almost the same, 23 in 1989 and 25 in 1990.

Relation of severity values to disease intensity. A set of cross comparisons were made between CDSV accumulated since transplanting and the disease parameters CPLAD and CPPD, observed one latent period later, as well as CUPLAD. In general the correlation coefficients were relatively low (Table 3.3). This is due to the absence of the disease in both years during approximately 70 days after transplanting.

Increase in disease with time was associated with increase in CDSV. The correlation between CDSV and the $CPLAD_{+LP}$ was positive and the correlation coefficients were 0.60 and 0.52 for inoculated plots and 0.49 and 0.50 for uninoculated plots, for 1989 and 1990, respectively (Table 3.3).

Also there was a positive correlation between CDSV and $CPPD_{+LP}$ in uninoculated plots. The correlation coefficients were 0.61 in 1989 and 0.75 for 1990 (Table 3.3). In inoculated plots the plants all were diseased in a short span of time.

A positive correlation was found between CDSV and

Table 3.3. Correlation coefficients and significance of cross comparisons between cumulative disease severity values (CDSV) and cumulative proportion of leaf area diseased (CPLAD), current proportion of leaf area diseased (CUPLAD) or cumulative proportion of plant diseased (CPPD). CPLAD and CPPD were calculated one LPB later. CPLAD and CUPLAD were calculated from uninoculated (A) and inoculated (B) plots during 1989 and 1990. CPPD were obtained from uninoculated (A) plot in 1989 and 1990.

	1989					1990				
	CPLAD		CUPLAD		CPPD	CPLAD		CUPLAD		CPPD
	A	B	A	B	A	A	B	A	B	A
CDSV	0.49	0.60	0.63	0.68	0.61	0.5	0.52	0.50	0.51	0.75
P	0.13	0.07	0.04	0.02	0.07	0.1	0.09	0.09	0.09	0.01

P level of significance

CUPLAD. The correlation was higher for inoculated (r=0.68 in 1989 and 0.51 in 1990) than for uninoculated plots (r=0.63 in 1989 and r=0.50 in 1990). The significance was higher in 1989 than in 1990. This indicates that CUPLAD must have served as source of secondary inoculum.

A model to predict disease. Two models (Eq 9 and Eq 10) to predict disease increase (DI) due to CUDSV were developed from seven and eight observations collected in 1989 and 1990, respectively (Table 3.4, 3.5).

$$DI = 0.0585 - 0.02578 * CUDSV \quad (9)$$

$$DI = 0.1830 - 0.06979 * CUDSV \quad (10)$$

where DI is disease increase and CUDSV is current disease severity value. The models had $R^2 = 0.89$ (Eq 9) and $R^2 = 0.79$ (Eq 10). In order to develop a single model the variances of these models were compared by the F test. Since a significant difference was found between variances the two years data were not pooled and it was not possible to develop a single model (Appendix 3.1 and 3.2). Observed and predicted values calculated from Equations 9 and 10 are presented in Fig 3.4 and Fig 3.5, respectively. The equations developed here had a high R^2. However, both the models describe an inverse relation between CUDSV and DI, which do not explain the biological pathway.

Table 3.4. Disease increase in septoria blight of celery corresponding to current disease severity values observed during 1989 in uninoculated plot. Disease increase for each wet period was calculated as the difference between CUPLAD on LPE and LPB since wet period.

Wet Period (Day of Year)	Current Severity Values	CUPLAD $_{+11PE}$ *		CUPLAD $_{+11PB}$ **		Disease Increase
		Day of Year	CUPLAD	Day of Year	CUPLAD	
219	2	233	0.00031	230	0.0000	0.00031
221	2	237	0.00468	233	0.00031	0.00437
224	2	240	0.00609	237	0.00468	0.00141
227	2	244	0.02444	240	0.00609	0.01835
232	1	247	0.06468	244	0.02444	0.04024
236	0	251	0.11988	247	0.06468	0.05520
239	1	254	0.15165	251	0.11988	0.03177

* Current proportion of leaf area diseased observed one LPE after a wet period.

** Current proportion of leaf area diseased observed one LPB after a wet period.

Table 3.5. Disease increase in septoria blight of celery corresponding to current disease severity values observed during 1990 in uninoculated plot. Disease increase for each wet period was calculated as the difference between CUPLAD on LPE and LPB since wet period.

Wet Period (Day of Year)	Current Severity Values	$CUPLAD_{+1LPE}$ *		$CUPLAD_{+1LPB}$ **		Disease Increase
		Day of Year	CUPLAD	Day of Year	CUPLAD	
217	2	232	0.00016	229	0.0000	0.00016
221	3	236	0.00421	232	0.00016	0.00405
224	2	239	0.04893	236	0.00421	0.04472
227	2	243	0.07363	239	0.04893	0.02470
230	1	246	0.17766	243	0.07363	0.10403
234	1	250	0.27986	246	0.17766	0.10220
237	1	257	0.42747	250	0.27986	0.14761
246	1	264	0.55696	257	0.42747	0.12949

* Current proportion of leaf area diseased observed one LPE after a wet period.

** Current proportion of leaf area diseased observed one LPB after a wet period.

Fig. 3.4. Observed and predicted values of disease increase for 1989. Each point represents the mean of seven observations in uninoculated plot. Predicted values were calculated by Equation 9.

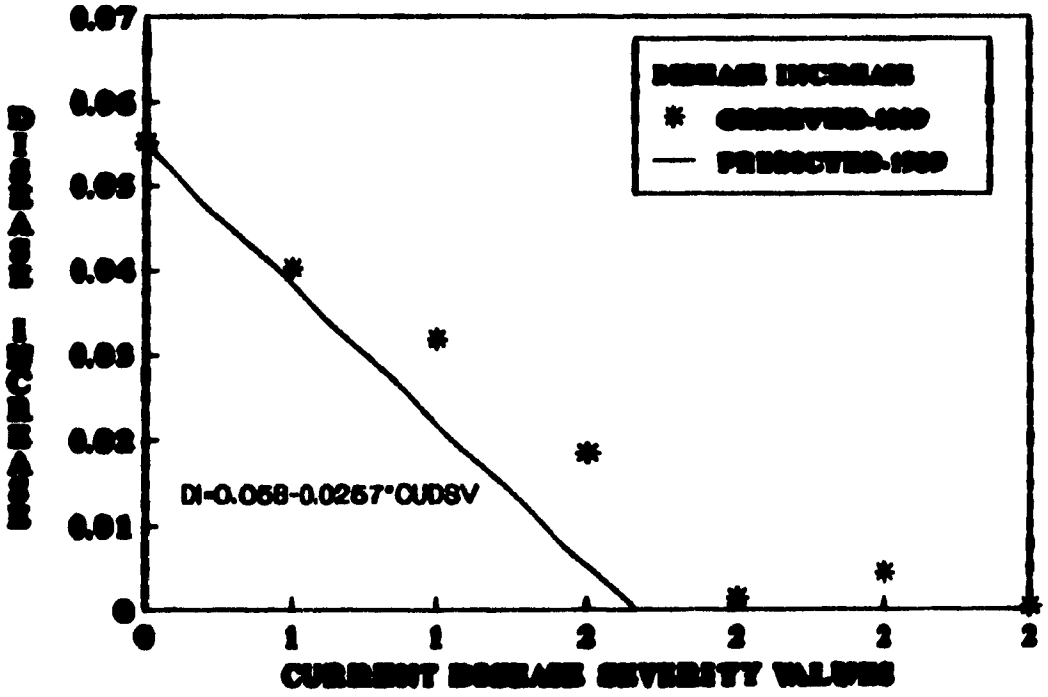
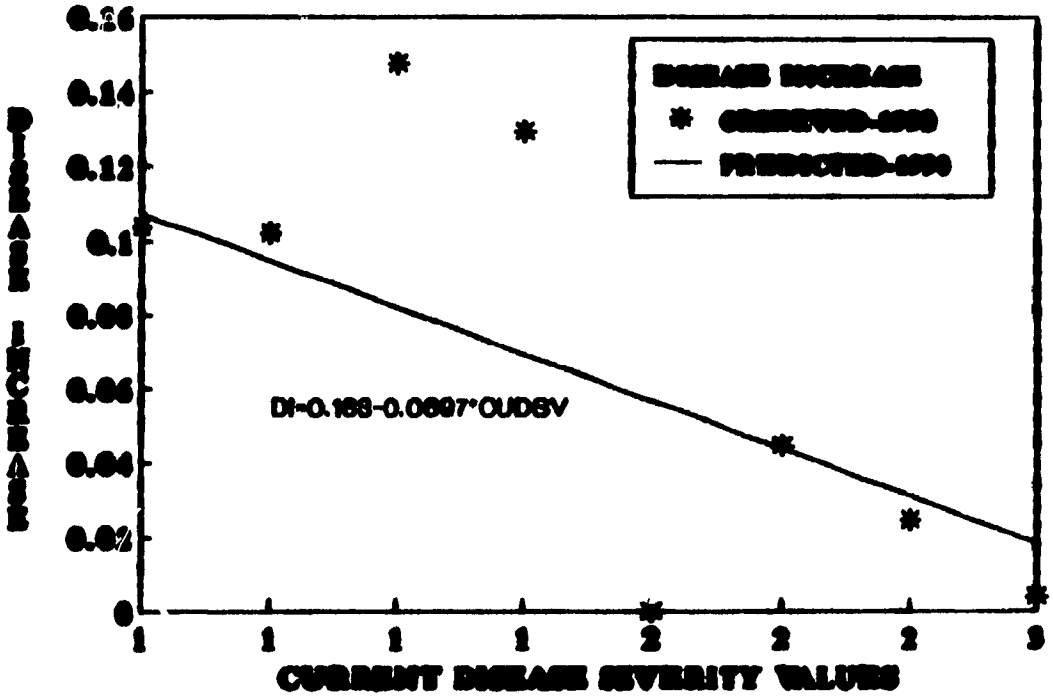

0.07
0.06
0.05
0.04
0.03
0.02
0.01
0
1
1
2
2
2
2
DI=0.058-0.0257*CUDSV

Fig. 3.5. Observed and predicted values of disease increase for 1990. Each point represents the mean of eight observations in uninoculated plot. Predicted values were calculated by Equation 10.


DISEASE INCREASE
OBSERVED-0510
PREDICTED-0510
DI=0.155-0.0697*CUDSV
0.16
0.14
0.12
0.1
0.08
0.06
0.04
0.02
0
1
1
1
1
2
2
2
3
CURRENT DISEASE SEVERITY VALUES

Equations were also developed to predict disease increase (DI) from CUPLAD. The CUPLAD was considered as source of inoculum and may be responsible for the increase in disease. This model, however, was not given here because the coefficient of determination was very low (R^2 = 0.21).

DISCUSSION

A severe epidemic of septoria blight of celery depends on initial inoculum surviving in plant debris or on the infected transplants that are coming from infected seeds (Maude and Shuring, 1970; Berger, 1970).

The spatial distribution of the initial inoculum or diseased plants, as well as the age of the crop when the first infection occurs is also very important. In this experiment the disease severity was quite high in inoculated plots indicating that initial inoculum plays a big role in the progress of septoria blight of celery. Thus, it is evident that the reduction of initial inoculum postpones the time at which an action threshold is reached. The importance of seed treatment to reduce initial inoculum has been identified and seed certification schemes have been recommended (Berger, 1970).

However, it is unclear in this research, what impact celery debris has on the appearance of the disease in the

field in both years, because of inoculum movement from the inoculated to uninoculated plot. Since the information available in literature on pathogen survival in soil is from experimentation conducted abroad, studies must be conducted under Quebec conditions to understand the importance of infected celery debris on inoculum survival.

Simple forecasts.

1. Based on initial occurrence of septoria blight. According to the Quebec Government (CPVQ, 1987) recommendation, the fungicides to control septoria blight of celery should be applied "when trnasplants are recovered". This was approximately 10 days after transplanting for the years 1989 and 1990. However, the disease in uninoculated plots did not appear until 77 days after transplanting. So the initial occurrence of disease can be used as an action threshold to initiate fungicide application.

Waiting for a longer time after initial disease occurrence could be very dangerous because the disease increases rapidly and would be very difficult to manage. Such a recommendation would require scouting in the field to note the time of disease appearance after transplanting. Such a forcasting system is being used by an integrated pest management program in Quebec. However before recommending to growers the validity of such a forecast must be tested under commercial conditions.

2. **Based on severity values.** In both years, the blight appeared for the first time 75 days after transplanting. The CDSV by this time was 23 in 1989 and 25 in 1990. Thus, a CDSV of 23 may be considered as an action threshold to start fungicide application. However, this may not represent the commercial situation, and hence the forecast must be validated before recommendation. Here, growers must be trained in using leaf wetness sensors and in calculating CDSV.

Blight increased very rapidly after its initial appearence. Thus, delaying fungicide application further, for example up to CPPD = 0.7, may be very dangerous. Lower levels of initial disease incidence threshold must be tested under comercial conditions to recommend disease incidence threshold to postpone fungicide application.

The second and subsequent fungicide applications could be sprayed after one wet period with a DSV score of 2. Following this recommendation two or four fungicide applications are required for each year as the CDSV were 25 and 29 for 1989 and 1990, respectively. Therefore, if the the forecasts proposed in this research are combined with the use of certified seed it is possible to save five to seven applications out of 10-15 applications required by the conventional method. This will result in a positive economic effect in production costs and in the reduction of damage to the environment. However, this forecast system must be

tested under field conditions before a final recommendation can be made.

The models to predict DI from CUDSV cannot be used either to time subsequent fungicide or to forecast disease. The models describe a negative relation between CUDSV and DI. According to this, favorable conditions for infection or larger CUDSV resulted in a decrease in DI. This may be because the development of septoria blight is not only associated with the environmental factors favorable to infection but also to other important components closely related with the development of the disease such as initial inoculum originating from the crop debris and dissemination, which were not considered here. Secondary inoculum plays a major role in infection. The CUPLAD, the lesions that produced spores, increased with the advance in the season. However, a model (not included here) based on spore producing disease area and CUDSV did not increase the coefficient of determination.

The decrease in DI with increase in CUDSV may also be due to the inherent problem associated with the calculation of DI. Here it is based on leaf area diseased and generally the infection depends on the increase in the number of infections. In septoria blight the increase in lesion size and the coalescense of lesions contribute to a false increase or reduction in DI later in the season. The physiological age of the plant at the time of infection

plays an important role on the development of septoria blight of celery. Older leaves are more suitable for infection and lesion expansion. This aspect brings up a confounding effect when the disease is assessed by a scale as it was here. The sensitivity of the scale is based on the ability of the user to distinguish between proportion of healthy and diseased tissue of the plant. Lack of sensitivity of the Horsfall-Barrat scale has been reported (Berger, 1970). Therefore, the model could be improved by calculating DI based on number of lesions and measuring the lesion size. Also, by counting the number of lesions it is possible to have a better estimate of the rate of increase in disease.

In addition, LPB and LPE were not predicted from mean minimum and mean maximum temperatures. Instead, a flexible range was used since the disease was quantified only at 3-4 day intervals. It was adjusted more towards LPB because 50% of the lesions were formed within the range of 12 to 14 days. These adjustments also reduced or increased DI falsely.

The development of a forecast model to manage septoria blight of celery is very complex. Such a model should require an accurate knowledge of the environmental factors that condition the biological processes of the disease cycle. The information available is scarce and the results are not accurate enough to be used in building up empirical

or fundamental models. One important reason for this difficulty is the inherent characteristics of the pathogen and its interaction with the host. The pycnidium is immersed in the host tissue. It controls the production, release, and germination of the spores. The conidial matrix produced by the pycnidium protects spores from unfavorable conditions. Pycnidia are produced in either apparently healthy or diseased tissue where they are protected. Thus, the environmental conditions surrounding the crop may or may not have a direct effect on the fungus. These weather factors are commonly studied and related to the disease development. Water-related factors also have a direct effect on spread of the disease, however, they are not subjected to study due to their complexity.

GENERAL DISCUSSION AND CONCLUSIONS

The importance of wetness in the development of septoria blight of celery is noticeable. Duration of leaf wetness is critical to get successful infection and also is considered the most important factor for disease spread (Berger, 1970; Mathieu, personal communication). In this work it was found that the number of spores increased with increasing relative humidity. A wet period of 48 hr at temperatures between 15 and 20 C resulted in the largest amount of spores produced per square millimetre of lesion area. However, no critical weather factors were determined for sporulation since spores were produced at various levels of relative humidity and temperature tested. These conditions are within the range of the best weather conditions for celery production, which minimizes the need of using the developed models for the prediction of spores in a forecast model. The lack of a critical level for spore production suggests the importance of testing a broader range of temperatures and relative humidity in order to find detrimental conditions for spore production.

Wetness has a concomitant effect on sporulation. In addition to favouring spore production, wetness is important to liberate the spores and release them from cirri by dilution. This effect was found after 48 hr at 20 C and could explain in part the fast disease spread under

continuous wetness or rainy periods described by other workers (Berger, 1970). In contrast, there is a negative effect of wetness on spore viability. Persistent wetness conditions reduced the viability of spores of Septoria tritici to 5% in 15 days (Gough and Lee, 1985). There is no information available about spore viability of Septoria apiicola as affected by duration of leaf wetness and further studies are required.

There is a complex situation in studying the sporulation process of Septoria apiicola. In this study, pycnidia of the fungus were observed in chlorotic area before typical symptoms appeared. Lesion appearance, therefore, is not a good indication to explain the start of the sporulation process to define the infectious period in septoria blight. There is a period of time between infection and pycnidia formation without symptoms development. Starting at this stage, spores are produced and a shorter infection cycle could exist. The number of crops of spores produced by pycnidia of Septoria apiicola, as well as the effect of aging pycnidia on spore production are unknown.

A mean latent period beginning at 12 days was determined by this study for Quebec conditions during a celery growing season of 1989. This value is within the range of latent period found by other workers (Berger, 1970; Sherf and Macnab, 1986). The mean latent period beginning is useful to calculate the onset of the disease under field

conditions. It is close to the mean latent period 50% which was 14 days. This shows that 50% of the lesions are formed within 14 days after inoculation and the rest until the latent period ending of 19 days. Latent period ending is an arbitrary measure. It does not mean that no more lesions are formed due to one inoculation. It explains only the duration of the period when 95% of lesions are developed. The difficulty in determining when absolute latent period takes place is due to the existing variation among infection units, host, and environmental factors.

Mean maximum and mean minimum temperatures were considered in developing the models to predict latent period. No information about leaf wetness duration was included. However there was a constant 72 hr period of wetness after inoculation which could explain the low variability within 15 plant-set of inoculated plants. The combination of temperature and leaf wetness was the major determinant of the latent period of Septoria nodorum (Shearer and Zadoks 1974).

Initial inoculum plays an important role in the development of septoria blight of celery. Sanitation measures, therefore, reduce the amount of initial inoculum and postpone the time at which an action threshold is reached. In uninoculated plots, initial symptoms of the disease were observed 77 and 79 days after transplanting in 1989 and 1990, respectively. If the common occurrence of the

blight is late in the season there is no reason to apply fungicides as early as transplanting time (CPVQ, 1987). So the initial occurrence of disease could be an action threshold to initiate fungicide application. A scouting program is needed to detect the disease. However, no final recommendation is possible without validation under commercial conditions.

Disease severity was higher in inoculated plots than in uninoculated. The cumulative proportion of leaf area diseased (CPLAD) was higher in 1990. For both years a CPLAD threshold of 0.005 was found to be approximately 85 days after transplanting. Up to this threshold the increase of the disease (DI) was relatively low. For the same time the cumulative proportion of plant diseased (CPPD) were 0.11 in 1989 and 0.09 in 1990, respectively. In order to diminish the risk of a rapid development of the disease between 85 and 95 days after transplanting, fungicide applications could be done once the CPLAD threshold was reached. Further validation is required under commercial conditions before final recommendation to growers.

Cumulative disease severity values are a useful approach to time fungicide application. At the time the disease was observed for the first time, the cumulative disease severity values (CDSV) were very close, 23 in 1989 and 25 in 1990. A CDSV of 23, therefore, may be considered as an action threshold to begin fungicide application. If

this method is followed, an intense training in measuring duration of wetness period, temperature and calculation of disease severity values is imperative.

Using the forecasts proposed here it is possible to reduce by five to seven fungicide applications that are commonly recommended in the conventional method of septoria blight management (CPVQ, 1987). After a successful first application, the subsequent fungicide could be applied after a wet period with a disease severity value of 2. A total of two or four fungicide applications are required for each year since the CDSV were 25 and 29 for 1989 and 1990, respectively. As pointed out above, the forecasts proposed need validation prior to final recommendation.

To calculate disease increase a flexible range of LPB and LPE was employed since the disease was quantified only at 3-4 day intervals. It was adjusted more to LPB than to LPE since 50% of lesions were formed within the range of 12 to 14 days.

Models developed here to predict disease increase as a function of current disease severity values (CUDSV) were not used to time subsequent fungicide application because CUDSV alone is a poor indicator of disease increase. As other factors are involved, additional studies such as initial inoculum and dissemination which are not considered here must be conducted.

The effect of infected celery debris on the occurrence

of the disease in the field is unclear and studies on this aspect under Quebec conditions are required. Extreme conditions during winter could be an important factor to reduce survival and viability of spores of Septoria apiicola in Quebec.

CLAIM TO ORIGINALITY

To the best of the author's knowledge these studies contain the following contributions:

1) This is the first report where the effect of relative humidity and temperature on sporulation of Septoria apiicola on living plants is studied. Results showed that the fungus produced spores at different levels of relative humidity (65, 88, 92, 96%, and wet) and temperature (15, 20, 25, 28 C). It also was found that a period of 48 hr at 20 C was optimum for a large production of spores.

2) This is the first report showing the duration of latent period for Septoria apiicola in celery under Quebec conditions. Mean latent period beginning of 12 days, mean latent period 50% of 14 days, and mean latent period ending of 19 days were established for forecasting purposes.

3) This is the first report where two alternatives to manage septoria blight of celery are presented. 1) Based on initial occurrence of septoria blight. The initial observation of the disease in the field could be used as an action threshold to initiate fungicide application. 2) Based on disease severity values. A cumulative disease severity values of 23 may be

considered as action threshold to start fungicide application. Using the forecasts proposed in this research it is possible to save five to seven applications of fungicide with a positive economic effect and reduction of damage to the environment.

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APPENDICES

Appendix 1.1. Analysis of variance on effect of duration (DW) of relative humdity (RH) on spore production by *S. apiicola* on celery cultivar Florida 683.

Source	df	Mean Square	Pr>F
Relative Humidity (RH)	4	64878.2688	0.0001 **
Block	1	19.4998	0.7148 ns
DW	5	37752.6484	0.0001 **
RH * DW	20	5890.1554	0.0001 **
Error a (Block*RH)	4	126.6630	
Error b (Block*DW(RH))	25	80.5837	

** significant at the 0.01 level
ns not significant

Appendix 1.2. Orthogonal contrast on effect of duration (DW) of relative humdity (RH) on spore production by S. apiicola on celery cultivar Florida 683.

Source	df	Mean Square	
Error	145	65.7866	
Contrast			Pr>F
DW (L) in RH 65	1	14038.1116	0.0001 **
DW (C) in RH 88	1	429.7092	0.0116 **
DW (C) in RH 92	1	4400.5754	0.0001 **
DW (Q) in RH 96	1	1804.6780	0.0001 **
DW (Q) in RH 100	1	74099.1001	0.0001 **

** significant at the 0.01 level
L linear
Q quadratic
C cubic

Appendix 1.3. Regression analysis on effect of duration (DW) of relative humidity (RH) on spore production by *S. apiicola* on celery cultivar Florida 683.

Source	df	Mean Square	Pr>F
RH^1	1	12203.1824	0.0001 **
RH^2	1	72553.7854	0.0001 **
DW	1	54358.1773	0.0001 **
RH * DW^1	1	5202.1386	0.0021 **
RH * DW^2	1	4269.6791	0.0050 **
RH^2 * DW^2	1	14568.8860	0.0001 **
Error	53	27.9465	

Parameter	Estimate	Pr>T
Intercept	165.29362	0.0001 **
RH^1	0.57882	0.0001 **
RH^2	0.02799	0.0001 **
DW	0.97790	0.0001 **
RH * DW^1	-0.00254	0.0001 **
RH * DW^2	0.00001	0.0056 **
RH^2 * DW^2	-0.00010	0.0001 **

** significant at the 0.01 level
R^2 = 0.86
CV = 12.76

Appendix 1.4. Analysis of variance on effect of duration of wetness (DW) and temperature (T) on spore production by S. apiicola on celery cultivar Florida 683.

Source	df	Mean Square	Pr>F
Temperature (T)	3	29153.1387	0.0003 **
Block	1	14.9958	0.7228 ns
DW	5	2544.3765	0.0001 **
T*DW	15	4350.3520	0.0001 **
Error a (Block*T)	3	98.780	
Error b (Block*DW(T))	20	97.6262	

** significant at the 0.01 level
ns not significant

Appendix 1.5. Orthogonal contrast on effect of duration of wetness (DW) and temperature (T) on spore production by S. apiicola on celery cultivar Florida 683.

Source	df	Mean Square	
Error	116	62.310	
Contrast			Pr>F
DW (Q) in T 15	1	6116.0161	0.0001 **
DW (C) in T 20	1	3198.2838	0.0001 **
DW (C) in T 25	1	1751.7456	0.0001 **
DW (C) in T 28	1	428.2838	0.0101 **

** significant at the 0.01 level
L linear
Q quadratic
C cubic

Appendix 1.6. Regression analysis on effect of duration of wetness (DW) and temperature (T) on spore production by S. apiicola on celery cultivar Florida 683.

Source	df	Mean Square	Pr>F
T	1	22299.3413	0.0001 **
T^2	1	6456.5187	0.0001 **
DW^2	1	2917.7872	0.0001 **
T * DW	1	6233.3072	0.0001 **
T^2 * DW^2	1	1302.6118	0.0039 **
T^2 * DW^2	1	5582.5029	0.0001 **
Error	47	31.3077	

Parameter	Estimate	Pr>T
Intercept	262.68484	0.0001 **
T	-8.25918	0.0001 **
T^2	-1.24981	0.0001 **
DW^2	-0.02427	0.0001 **
T * DW	-0.07762	0.0001 **
T^2 * DW^2	0.00066	0.0005 **
T^2 * DW^2	0.00006	0.0001 **

** significant at the 0.01 level
R^2 = 0.80
CV = 7.43

Appendix 2.1. Regression analysis on effect of mean maximum temperature (MTXB) and mean minimum temperature (MTMB) on latent period begining (LPB) of septoria blight of celery.

Source	df	Mean Square	Pr>F
MTXB	1	70.9978	0.0001 **
MTMB	1	124.9625	0.0001 **
Error	126	1.1340	

Parameter	Estimate	Pr>T
Intercept	-9.4115	0.0001 **
MTXB	1.7000	0.0001 **
MTMB	-1.3988	0.0001 **

** significant at the 0.01 level
R^2 = 0.56
CV = 9.12

Appendix 2.2. Regression analysis on effect of mean maximum temperature (MTXE) and mean minimum temperature (MTME) on latent period ending (LPE) of septoria blight of celery.

Source	df	Mean Square	Pr>F
MTXE	1	343.7590	0.0001 **
MTME	1	38.6059	0.0001 **
Error	126	2.4061	

Parameter	Estimate	Pr>T
Intercept	-10.6315	0.0001 **
MTXE	1.7073	0.0001 **
MTME	-0.9352	0.0001 **

** significant at the 0.01 level
R^2 = 0.54
CV = 8.17

Appendix 3.1. Regression analysis on the effect of current disease severity values (CUDSV) on disease increase of septoria blight of celery scored from uninoculated plot in 1989.

Source	df	Mean Square	Pr>F
CUDSV	1	0.002468	0.0012 **
Error	1	0.000055	

Parameter	Estimate	Pr>T
Intercept	0.058492	0.0002 **
CUDSV	-0.025779	0.0012 **

** significant at the 0.01 level

Appendix 3.2. Regression analysis on the effect of current disease severity values (CUDSV) on disease increase of septoria blight of celery in uninoculated plot in 1990.

Source	df	Mean Square	Pr>F	
CUDSV	1	0.0188714	0.0028	**
Error	1	0.0008004		

Parameter	Estimate	Pr>T	
Intercept	0.183021	0.0004	**
CUDSV	-0.025779	0.0028	**

** significant at the 0.01 level