Introduction

Since the early 1990’s, fusarium head blight (FHB) caused by *Fusarium graminearum* (Schwabe), has become one of the most significant cereal diseases faced by producers in Manitoba and the Midwestern United States (McMullen 1997b; Tekauz et al. 2000; Gilbert and Tekauz 2000). Infection of cereal heads by this pathogen can result in significant yield losses, but more importantly the resulting visibly damaged kernels can reduce the grade, and therefore the value, of the harvested crop (Martens et al. 1988; Mathre 1997; Menzies and Gilbert 2003; Wiese 1987). Furthermore, the fungus can produce several mycotoxins, including deoxynivalenol (DON) and zearalenone. In non-ruminants, DON contaminated feed can reduce growth rates while zearalenone can cause reproductive problems. Barley (*Hordeum vulgare* L. emend. Bowden) infected with *F. graminearum* can cause problems for the malting and brewing industries due to the phenomenon known as gushing or excessive foaming. Many malting companies will reject barley for malt if it is found to contain detectable levels of DON.

From the mid to late 1990’s *F. graminearum* was the main *Fusarium* spp. isolated from cereal heads, seed, and fusarium damaged kernels (FDK) in Manitoba (Clear et al. 1996; Clear and Patrick 2000; Clear et al. 2000, 2002; Gilbert et al. 1998, 1999; McCallum et al. 1997, 1998; Tekauz et al. 1996, 2000). In 1986 and 1987, *F. graminearum*, *F. avenaceum*, and *F. sporotrichioides* were the main *Fusarium* spp. isolated from Manitoba cereal seed samples containing FDK (Clear and Patrick 1990). Surveys in 1995, 1996, and 1997 indicated that that *F. graminearum* was a rarely found species in barley grain from Saskatchewan, but was found at seed infection levels of 1 to 36% in Manitoba (Clear et al. 2000). In wheat, *F. avenaceum* was the most commonly found *Fusarium* spp. associated with FDK from Saskatchewan (Clear and Patrick 1990, 2000); however, *F. graminearum* started to become more common in 1997 and 1998, especially in the south-eastern parts of the province. Clear et al. (2000) reported that *F. graminearum* was not detected on barley seed in Alberta and was seldom associated with FDK’s of wheat in Alberta, especially in the central and northern cropping regions (Clear and Patrick 2000). Turkington et al. (2002) also found that *F. graminearum* was not detected in barley and wheat grain samples collected from central and northern from 1995-1997. However, the appearance of low levels of FDK’s due to *F. graminearum* in Alberta from 1999-2001 (Clear and Patrick 2000; Clear 2002) has raised concerns regarding the potential development of FHB due to *F. graminearum* in the western Prairie region.

Yearly surveys for symptoms of FHB and FDK due to *F. graminearum* have continued (Turkington et al. 2003, 2004; Clear 2005), and these activities provide an ongoing assessment of the prevalence and spread of this disease issue. However, an understanding of potential long-term distribution and severity of FHB caused by *F. graminearum* is critical for developing appropriate monitoring programs and management strategies for emerging disease issues. Climate is an important determinant of pest species distribution and abundance and this relationship has been used by the computer simulation program, CLIMEX™ (Sutherst et al. 1999) to estimate potential distribution and abundance of pest species. The simulation program is based on climate and uses an inferential approach to forecasting potential pest distribution and abundance. CLIMEX™ has been applied to different biological entities including several insect pest species in Canada (Sutherst et al. 1999; Dosdall et al. 2002; Mason et al. 2003; Olfert et al. 2004). The objective of this component of the current paper was to forecast the potential distribution and abundance
(severity) of *F. graminearum* in wheat using the computer simulation program – CLIMEX™ under both current long-term climatic conditions and potential climate change scenarios.

Clubroot, caused by *Plasmodiophora brassicae*, was detected for the first time in 12 canola fields in Alberta in 2003 (Tewari et al. 2004). The identification of clubroot on the Alberta canola crop is a concern as the disease is associated with appreciable yield losses and it can only be managed with extended intervals between host crops. Unfortunately, other management strategies may be too expensive to implement or are of limited effectiveness. With the initial appearance of clubroot on canola in 2003 there is concern regarding the potential risk to canola production across the entire prairie ecozone. The objective of this component of the current paper was to develop a very preliminary forecast the potential distribution and abundance (severity) of clubroot, caused by *P. brassicae*, in canola using the computer simulation program – CLIMEX™ based on current long-term climatic conditions.

**Materials and Methods**

CLIMEX™ is a computer simulation program that can be used to estimate potential distribution and abundance of pest species based on climatic conditions (Sutherst et al. 1999). The initial steps of using the program involve selecting values for parameters that describe pest species response to temperature and moisture in the case of plant pathogens, and also light for insect pests. Based on weekly responses to temperature and moisture, weekly growth and stress indices are calculated. From the weekly responses to temperature and moisture an annual ecoclimatic index is derived from the growth and stress indices. The ecoclimatic index provides a measure of the favourableness of location for pest survival and abundance. For more information on the derivation of weekly responses to temperature and moisture, and calculation of weekly growth and stress indices and annual ecoclimatic indices consult the CLIMEX™ manuals and previous publications (Sutherst et al. 1999; Kriticos and Randall 2001; Kriticos et al. 2000).

**Fusarium head blight**

Specific CLIMEX™ model parameters for temperature and moisture for FHB were based on previously published information (Anderson 1948; Anon. 2002; Clear and Patrick 2000; McMullen et al. 1997a,b; Shaner 2002; Sutton 1982; Parry et al. 1995), recent distribution and disease occurrence in epidemic areas (Clear 2002; 2005), and an iterative process.

For FHB the following temperature parameters were used in the model:

- Limiting low temperature  (12.5°C)
- Lower optimal temperature  (15.0°C)
- Upper optimal temperature  (30.0°C)
- Limiting high temperature  (32.0°C).

Soil moisture parameters used for FHB were based on an iterative process and the documented distribution of FHB. In addition, a dry stress factor was also included in the parameter set to account for the negative influence of dry conditions on the potential for disease development. An irrigated scenario was also developed based on a growing season moisture deficit of 250 mm for the irrigated regions of southern Alberta (R. Dunn, Alberta Agriculture, Food and Rural Development, Lethbridge, AB, personal communication). Within the simulation an irrigation regime of 15.35 mm per week was followed for the growing season. Finally, climate change scenarios of +2, 4, or 6°C temperature increases, with or without a 20% increase in rainfall were also evaluated for FHB only.

Temperature and rainfall data used for the FHB simulation (CLIMEX™ V1.1, Sutherst et al. 1999) were based on long-term climate normals data from Environment Canada for 1971-2000, and daily data for some locations from 1995-2003.
Clubroot

For the preliminary CLIMEX™ model for clubroot, temperature and moisture parameters were based on previously published information, disease occurrence in epidemic areas (Hartman 2004; Tremblay et al. 1999; Monteith 1924; Rimmer et al. 2003; Wallenhammar 1999), and an iterative process.

For clubroot the following temperature parameters were used in the model:

- Limiting low temperature: (12.0°C)
- Lower optimal temperature: (18.0°C)
- Upper optimal temperature: (25°C)
- Limiting high temperature: (27.0°C)

Soil moisture parameters used for clubroot were based on an iterative process and the documented distribution of clubroot, as well as published information (Monteith 1924) that indicated that resting spore germination could occur at as low as 45% of water-holding capacity. In addition, a dry stress factor was also included in the parameter set to account for the negative influence of dry conditions on the potential for disease development.

CLIMEX™ (V2.0, Hearne Scientific Software Pty Ltd., Melbourne VIC, Australia, www.hearne.com.au) was used for the clubroot simulation and utilized climate data from the Climatic Research Unit, University of East Anglia, Norwich UK (http://www.cru.uea.ac.uk/cru/cru.htm). Climate data were based on the surface climatology of global land areas for a 0.5° lat × 0.5° long grid, and were constructed from a dataset of station 1961–90 climate normals, where station data were interpolated as a function of latitude, longitude, and elevation.

Ecoclimatic index values

For both FHB and clubroot CLIMEX™ analyses the annual ecoclimatic index (EI) values described the suitability of locations for species survival and reproduction. Ecoclimatic index values in terms of suitability of a location for pest species survival and development can be categorized as follows (Sutherst et al. 1999; Dosdall et al. 2002; Olfert et al. 2004):

- 0 = not suitable
- 1 to 10 = generally unfavourable for survival and reproduction
- 10 to 19 = marginal
- 20 to 25 = favourable
- >25 = very favourable.

In general, values of 10-20 indicate areas were the pest species of concern is predicted to not have an economic impact, while values above 20 indicate areas where the pest is predicted to have an economic impact. Ecoclimatic index values for FHB and locations for western Canada were imported into ArcView (GIS 8.1) to develop contoured maps. For the clubroot simulation the built-in capability of CLIMEX™ V2.0 was used to generate a grid map of EI values for Canada. The ecoclimatic index categories are based on climate normal data. Deviations, due to variability of annual weather, may result in significant economic impact, even in locations that are categorized as marginal.

Results and Discussion

*Fusarium head blight*

Derived EI values were compared to the documented distribution and abundance of FHB in the eastern prairies to assist with validation of model parameters. Ecoclimatic index values generally reflected the development and level of FHB caused by *F. graminearum* in the eastern prairies, with the highest EI...
values for the Red River Valley region, where this disease is well-established and causes economic impacts (Fig. 1a). Daily climatic data were also used to compare yearly fluctuations in CLIMEX™-derived EI values and weekly fluctuations in temperature and moisture indexes, with FDK levels as reported by the Canadian Grain Commission (Clear 2005). In general, annual variation in FDK levels, especially in Manitoba Crop Districts 7-9 reflected yearly fluctuations in EI values (data not shown). As a consequence, the CLIMEX™ temperature and moisture parameters that were developed were then used to forecast the potential distribution and severity of FHB caused by \( F. graminearum \) for the central and western Prairie region. Based on current long-term conditions, the model predicted that \( F. graminearum \) could expand to encompass large areas of Saskatchewan and Alberta (Fig. 1a). In particular, the Edmonton region could be expected to have disease levels that approach those currently experienced in the eastern prairies. In the drier regions of the central and western Prairies, FHB caused by \( F. graminearum \) was not predicted to have an economic impact. In general, the CLIMEX™ model for FHB demonstrated that \( F. graminearum \) was more sensitive to soil moisture than temperature; changes in moisture parameters resulted in larger changes in EI values compared to modifying temperature parameters (data not shown). Annual/seasonal weather patterns also appear to influence the potential distribution and abundance of FHB caused by \( F. graminearum \). There was an expansion of areas where FHB may occur at economic levels with above-average (120% of normal) rainfall during the growing season (Fig. 1b).

Ecoclimatic index values developed for an irrigated scenario indicated that irrigation may compensate for dryer atmospheric conditions in some regions, potentially resulting in FHB levels similar to those occurring in the eastern prairies (Fig. 1c). This prediction is consistent with the observed development of FHB caused by \( F. graminearum \), especially in irrigated regions of Alberta (Turkington et al. 2003, 2004, Clear 2005). Climate change simulations with CLIMEX™ indicated that temperature increases of 2 or 4°C with a 20% increase in seasonal rainfall resulted in the greatest projected increase in the potential range and severity of \( F. graminearum \) (data not shown).

\section*{Clubroot}

Preliminary assessments of the potential distribution and severity of the club root pathogen in Canada predicted the occurrence of clubroot in areas where it has already been found to be a problem on vegetable species. Ecoclimatic values generally reflected the relative impact of clubroot in certain regions such as the lower mainland of British Columbia, Ontario, Quebec, and parts of the Maritimes, where clubroot can be an on-going problem in cruciferous vegetables (Hartman 2004; Tremblay et al. 1999; Rimmer et al. 2003). Temperature and moisture parameters were then used in CLIMEX™ to forecast the potential distribution and abundance of clubroot in western Canada. The CLIMEX™ model predicted the potential occurrence of club root on canola in the south-eastern corner of Manitoba and in the Edmonton region (Fig. 1d). The prediction of the occurrence of clubroot in the Edmonton area is consistent with past observations of this disease on cruciferous vegetables and canola in this region (Hartman 2004; Tewari et al. 2004; Tremblay et al. 1999). In general, EI values for the Edmonton region and south-eastern Manitoba predicted that clubroot would likely not be an economic problem based on long-term climatic conditions. However, above-average rainfall may increase the risk of this disease in these areas where canola and cruciferous vegetables are grown. Ecoclimatic index values from CLIMEX™ appear to indicate that there is a relatively low potential for development of clubroot in other regions of the prairie ecozone, which is likely due to drier climatic conditions.

\section*{Conclusions}

Awareness and management strategies are needed for areas predicted to be at risk for FHB caused by \( F. graminearum \). In the irrigated regions of Alberta and Saskatchewan, careful water management may be used to limit FHB risk while meeting crop water needs (McLaren et al. 2003). In both irrigated regions, and dryland regions where FHB is forecast to have a potential economic impact there should be on-going monitoring for \( F. graminearum \) in harvested grain and crop residues to identify any emerging problems.
For projected at risk areas extension activities should also be undertaken to inform producers of potential risk and to encourage monitoring and adoption of management strategies to limit FHB risk. Practices that reduce the build-up of infested residues and limit disease risk include: crop rotation, variety choice, quality seed, and fungicides (products registered for use on seed or in-crop).

Although CLIMEX™ predictions for clubroot of canola suggest that it is unlikely to be an economic problem for most of the prairie region, awareness and adoption of management strategies may still be useful for areas where the clubroot pathogen has already been observed. For these areas surveys should be conducted to monitor fields for clubroot symptoms and *P. brassicae*, while extension activities can be used to inform producers of potential risk and to encourage monitoring, and adoption of management strategies such as extended crop rotations away from canola and the removal of potentially contaminated soil from field equipment. Finally, research is needed to develop a better understanding of clubroot risk and its management in canola under western Canadian conditions.

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**References**


Figure 1. Ecoclimatic index (EI) values for *F. graminearum* (a-c) under current (a), above-average rainfall (b) and irrigated (c, green circles indicate irrigated regions of western Canada) scenarios. Ecoclimatic values for *P. brassicae* under current climatic conditions (d). In general, EI values of $\leq 10$ = generally not present; EI $>10$ to $<20$ = sub economic; EI $\geq 20$ to $\leq 25$ = economic impact; EI $>25$ = Chronic presence.

### Dryland Threat Scenario EI values

- **<=10** – Limited impact
- **>10 to <20** – Generally not economic
- **>=20 to <=25** – Economic
- **>25** – Chronic economic impact
Dryland Threat Scenario
EI values (120% of normal moisture)

- <=10 – Limited impact
- >10 to <20 – Generally not economic
- >=20 to <=25 – Economic
- >25 – Chronic economic impact
Irrigated Threat Scenario El values

- <=10 – Limited impact
- >10 to <=20 – Generally not economic
- >=20 to <=25 – Economic
- >25 – Chronic economic impact
Dryland Clubroot Scenario EI values

- Limited impact
- Generally not economic
- Economic