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Quantifying cropping practices in relation to inoculum levels of *Fusarium graminearum* on crop stubble

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This study was conducted in 58 producer-field locations in Manitoba from 2003 to 2006 to understand how cropping practices influence *Fusarium graminearum* inoculum levels on stubble of various crops, including wheat, collected from the soil surface. Colonies per m^2 (CN) were determined and converted to base-10 logarithm values ($\log_{10}$CN). Mean $\log_{10}$CN of the sampled field for various crops and groups of crops grown in the 3 years prior to sampling were tested to find significant differences. Average $\log_{10}$CN values were also used to determine significant differences between tillage systems and the effect of number of years. Average $\log_{10}$CN values for zero and minimum tillage systems were not different but were significantly higher than values for conventional tillage. A series of three crop rotation scenarios were tested using weighted $\log_{10}$CN values for crop, tillage, their interaction and their squared terms in step-wise regression models to identify which model was the best predictor of $\log_{10}$CN. This was selected as the cropping practice index (CPI) model and was expressed as: $\text{CPI} = 1{\cdot}98423 + 0{\cdot}55975\,(C_2 \times C_1 \times T)^2 + 0{\cdot}4390\,(C_2 \times T)^2$, where C_1, C_2 and T represent the weighted $\log_{10}$CN values for crops grown 1 and 2 years previously and tillage system, respectively. R^2 value for this model was 0·933 ($P < 0{\cdot}0001$). The reliability of the CPI model was tested using jack-knife full cross-validation regression. The resulting R^2 was 0·899. The CPI model was tested using data collected from seven wheat fields in 2006 ($R^2 = 0{\cdot}567$). The relationship between CPI and FHB index ($R^2 = 0{\cdot}715$) was significant.

Keywords: crop debris, disease management, fusarium head blight of wheat, *Gibberella zeae, Triticum aestivium*

Introduction

Wheat is one of the most important crops in the world, and fusarium head blight (FHB) disease has become one of its most significant diseases. This destructive disease is caused by the fungus *Gibberella zeae* (anamorph: *Fusarium graminearum*) in North America. Since 1993, FHB disease has become a major problem in Canada (Gilbert & Tekauz, 2000). FHB causes reduced wheat yield due to shrunken kernels, lower grades and physical quality due to reduction of test weight, and reduced bread loaf volume. FHB also threatens the safety of human food and animal feed because of mycotoxins produced by the pathogen (Dexter & Nowicki, 2003).

In Canada, economic losses to FHB for wheat were estimated at US $220 million in Central Canada, and at US $300 million in Manitoba from 1993 to 1998 (Windels, 2000). In the United States, wheat and barley losses to this disease were estimated at US $3 billion in the 1990s. Epidemics of FHB are favoured by high-moisture weather conditions, planting of susceptible wheat cultivars, and increasing levels of zero or minimum tillage, which contribute to a buildup of fusarium inoculum (Windels, 2000).

The prevalence of FHB has resulted in considerable research aimed at controlling it through agronomic practices, most notably via crop rotation and tillage. FHB was significantly reduced by wheat rotation with non-wheat and corn crops in US based studies (McMullen *et al.*, 1997). Elsewhere, crop rotation was found to significantly control FHB (Sutton, 1982; Parry *et al.*, 1995; Dill-Macky & Jones, 2000). The effect of wheat rotation with non-host crops on reducing FHB is most likely due to reduction of the amount of infested wheat stubble on the soil surface (Teich & Nelson, 1984; Windels & Kommedahl, 1984; Parry *et al.*, 1995; Dill-Macky & Jones, 2000). Recently, canola, field pea, bean and flax stubble were found to harbour *F. graminearum* (Chongo *et al.*, 2001). The stubble of these crops would likely become a potential inoculum reservoir for a wheat crop grown in the following year. The importance of controlling FHB disease by tillage is also significant (Miller *et al.*, 1998). Intense mouldboard ploughing significantly reduces FHB disease compared to chisel and zero tillage (Dill-Macky & Jones, 2000). In the soil, wheat stubble is partly decomposed in 24 months (Parry *et al.*, 1995; Pereyra *et al.*, 2004). Cereal stubble burning in the previous year was found to lower FHB disease levels in the current year

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(Dill-Macky & Salas, 2002). Therefore, epidemics of FHB disease are obviously influenced by crop species, sequence of rotated crops, frequency of host crops in the rotation, and tillage practices employed.

Fusarium graminearum is the predominant *Fusarium* species in North America. Its presence and its level of inoculum in crop stubble is undoubtedly a reflection of the effect of cropping practices. It is important to further understand how cropping practices affect FHB in order to provide wheat growers with more reliable and accurate strategies for disease management. Accordingly, the objectives of this study were to quantify the effects of cropping practices, i.e. crop rotation and tillage, on *F. graminearum* inoculum levels in various crop stubble including wheat, and to develop a model to express this relationship.

Materials and methods

Wheat fields and measurement

The study was conducted in cooperation with several producers who were seeding spring wheat in Manitoba from 2003 to 2006. There were 58 site-years in total (Table 1). Each field in this study was sown and managed by the producer according to his normal practices. The producers left a fungicide-free area within each field for the purposes of this study. In 2003, seven fields were sown to Canadian Wheat Red Spring (CWRS) wheat cv. Superb, and the other seven fields were sown to cv. AC Barrie (Anonymous, 2006). In 2004, nine fields were sown to Superb and another nine fields were sown to AC Barrie. In 2005, ten fields were sown to Superb and nine fields were sown to AC Barrie. In 2006, three fields were sown to Superb and four fields were sown to AC Barrie. It should be noted that the fields were generally different each year as a result of crop rotation practices. Information on previous crops grown on each field (crop rotation) and tillage methods (zero, minimum and conventional tillage systems) in the previous 3 years was obtained from the wheat growers.

In each field, crop stubble was collected 7 days after seeding from four sampling sites lined up approximately 20 m apart in each field. Each sampling site was 0·5 × 0·5 m. Crop stubble was dried at 25°C for 10 days in the drying room. It was then weighed and 10% of the

Table 1 Crop rotation and tillage of individual fields in Manitoba from 2003 to 2006

Field number	Crop rotation[a]	Tillage[b]	Year	Field number	Crop rotation	Tillage	Year
1	C-W-C-W	ZT	2003	30	C-W-F-W	MT	2004
2	C-W-C-W	MT	2003	31	C-W-C-W	ZT	2005
3	F-W-C-W	MT	2003	32	C-W-C-W	MT	2005
4	C-W-C-W	CT	2003	33	C-W-C-W	MT	2005
5	C-W-C-W	CT	2003	34	C-W-C-W	MT	2005
6	C-W-C-W	ZT	2003	35	F-W-C-W	CT	2005
7	C-W-C-W	MT	2003	36	P-W-C-W	CT	2005
8	W-P-C-W	CT	2003	37	W-P-C-W	CT	2005
9	C-W-P-W	CT	2003	38	W-F-C-W	MT	2005
10	W-C-P-W	CT	2003	39	C-W-C-W	MT	2005
11	C-W-S-W	ZT	2003	40	C-W-C-W	ZT	2005
12	W-f-P-W	MT	2003	41	C-W-C-W	MT	2005
13	W-W-F-W	CT	2003	42	W-W-C-W	MT	2005
14	W-C-F-W	MT	2003	43	F-W-C-W	CT	2005
15	W-C-W-W	CT	2004	44	P-W-C-W	ZT	2005
16	W-C-W-W	MT	2004	45	F-W-C-W	CT	2005
17	F-C-W-W	ZT	2004	46	F-F-C-W	ZT	2005
18	W-C-W-W	CT	2004	47	F-W-C-W	CT	2005
19	C-W-C-W	ZT	2004	48	W-S-C-W	MT	2005
20	C-W-C-W	MT	2004	49	C-W-F-W	MT	2005
21	C-W-C-W	MT	2004	50	W-W-F-W	MT	2005
22	W-W-C-W	CT	2004	51	W-F-f-W	CT	2005
23	W-P-C-W	CT	2004	52	C-W-C-W	CT	2006
24	W-f-C-W	CT	2004	53	C-W-C-W	CT	2006
25	F-W-C-W	MT	2004	54	C-W-P-W	MT	2006
26	f-W-C-W	CT	2004	55	W-P-C-W	CT	2006
27	W-P-C-W	MT	2004	56	F-W-C-W	CT	2006
28	W-C-F-W	MT	2004	57	C-W-F-W	MT	2006
29	C-W-f-W	ZT	2004	58	W-F-C-W	MT	2006

[a] W-C-W-W indicates a crop rotation of wheat, wheat, canola and wheat grown in the current year, and 1, 2 and 3 years before. W, wheat; C, canola; S, soybean; P, pea; F, flax; f, fallow.

[b] ZT, zero tillage; approximately 50–75% of the soil was covered by stubble. MT, minimum tillage; 30–50% of the soil was covered by stubble. CT, conventional tillage, <30% of the soil was covered by stubble.

stubble by weight was randomly selected, and cut into 5- to 20-mm pieces. The stubble was surface sterilized using bleach of 1% NaOCl for 1 min, air-dried on sterile filter paper, placed on potato dextrose agar (PDA) medium, incubated in light at 24°C, and observed for colony growth each day. The colonies were marked and numbered, then transferred to a fresh PDA medium for identification of *F. graminearum*. Initial identification based on the colour of colonies on the PDA medium was performed according to the standard keys described by Nelson *et al.* (1983). *Fusarium graminearum* was further identified based on the spore size and shape (Booth, 1971).

Wheat heads were sampled from the same fields 21 days after anthesis, from four other sampling sites of $0{\cdot}5 \times 0{\cdot}5$ m, and parallel to the stubble sampling sites. There were approximately 100 wheat heads collected in each sampling site.

Data analysis and quantification of cropping practices

Fusarium graminearum colonies per m^2 (CN) was computed based on the number of colonies formed on the crop stubble cultured on the PDA medium. The raw data were transformed to a base-10 logarithm because of the large range in values. The effect of crop rotation was quantified using the $\log_{10}$CN level measured in each field and assigning that value to each crop grown in each of the 3 years preceding the sampling year. Mean $\log_{10}$CN values were calculated for various combinations of crops grown in a specific number of years prior to the date of sampling (e.g. the mean $\log_{10}$CN value for all fields in which wheat was grown the previous year was 3·69; Table 2). Tillage was also quantified according to the mean $\log_{10}$CN level for fields that were in zero, minimum or conventional tillage. The effect of years were analysed based on the average $\log_{10}$CN value for all crops grown 1 year before, 2 years before or 3 years before.

The *t* test in the Fisher's least significant difference (LSD) procedure ($P < 0{\cdot}0001$) (SAS, version 9·1) was used to determine differences for the $\log_{10}$CN value between combinations of crops and tillage, in which the null hypothesis was that all combinations of crops had the same $\log_{10}$CN value (Table 2).

If the mean $\log_{10}$CN for crops or groups of crops were significantly different from each other within a crop year, the crop or groups of crops were assigned a weighted value corresponding to the mean $\log_{10}$CN. A weighting was calculated as the mean $\log_{10}$CN value for this crop or group divided by the smallest mean $\log_{10}$CN value in the rotation scenario and multiplied by the corresponding year score.

Development of CPI models

Cropping practice index (CPI) models were based on the $\log_{10}$CN weightings associated with each of the cropping practices evaluated in this study. Regression models were developed using the weightings for crop rotation, tillage, as well as the interaction of these factors and the square of these factors as independent variables. Three different crop rotation scenarios showed significant differences in $\log_{10}$CN level for either 1 year before or 2 years before. For each of the three rotation

Table 2 Logarithm of the numbers of *Fusarium graminearum* colonies on various crop stubbles per square metre of soil for different crops grown 1, 2 and 3 years before

Crop	Mean $\log_{10}$CN[a]	Crop	Mean $\log_{10}$CN	Crop	Mean $\log_{10}$CN	Crop	Mean $\log_{10}$CN
One year before							
Wheat	3·69 a	Wheat	3·69 a	Wheat/canola	3·62 a		
Canola	3·52 ac	Others	3·49 a	Others	3·39 b		
Soybean/pea	3·30 bcd						
Flax	3·49 ade						
Fallow	3·25 bce						
Two years before							
Wheat	3·60 a	Wheat	3·60 a	Wheat	3·60 a	Wheat/canola	3·58 a
Canola	3·48 ac	Canola/Soybean/Pea	3·39 b	Others	3·31 b	Others	3·19 b
Soybean/pea	3·26 bc	Flax/Farrow	3·12 c				
Flax	3·12 b						
Fallow	3·12 b						
Three years before							
Wheat	3·35 a	Wheat	3·35 a	Wheat/Canola	3·50 a		
Canola	3·64 b	Others	3·60 b	Others	3·52 a		
Soybean/pea	3·65 ab						
Flax	3·50 ab						
Fallow	3·33 ab						

[a] Mean base-10 logarithm of the numbers of *F. graminearum* colonies per square metre ($\log_{10}$CN). Differences in $\log_{10}$CN between crops were tested using the *t* test in the Fisher's least significant difference (LSD) procedure ($P < 0{\cdot}0001$) (SAS, version 9·1).

Different letters indicate significant difference between crops within previous crop year category.

scenarios, $\log_{10}$CN regression models were developed using a stepwise linear regression procedure (SAS, version 9·1) based on the weightings for crop and tillage in each scenario.

The variance inflation factor (VIF) was used for evaluating multicollinearity, and is expressed as $1/(1-R_i^2)$, where R_i^2 was the coefficient of determination for regression of the ith independent variable on all the other independent variables (Longnecker & Ott, 2004). When the VIF value was <10, multicollinearity was not significant, and the correlated variable stayed in the model.

The regression model with the greatest coefficient of determination (R^2) value among the three models tested was selected as the CPI model and used for $\log_{10}$CN prediction based on cropping practices. Thus, the CPI model provided a predicted $\log_{10}$CN value based on the scores for crop rotation and tillage in the previous 2 years.

Model validation

Reliability of the CPI model was estimated using the jackknife full cross-validation method (Walker, 2007). A series of n prediction models M_n were developed using the data collected from all 58 fields. To test each model, the data were split into two parts; the first part included the data collected from 'n−1' fields, and the second part included the data from the remaining field. The data from 'n−1' fields were used for fitting a model $M_{(n-1)}$, which was developed using the same variables as the model M_n. The data from the remaining field was used for validation of the model $M_{(n-1)}$. When this was completed for each of n fields, it provided a full cross validation data set, where for each field there was both an independent measured value and a predicted value based on the relationship determined independently from data for all the other fields. A linear regression between actual and predicted $\log_{10}$CN model was performed.

Data analysis of FHB

A fusarium head blight (FHB) index (%), using a 0 to 100% scale, was calculated as the percentage of infected spikes multiplied by the percentage of infected spikelets and divided by 100 (Gilbert *et al.*, 1995). Base 10 logarithm values of FHB index were grouped and averaged using the same method as that for the $\log_{10}$CN logarithm values. A linear regression was calculated for the relationship between CPI and logarithm $\log_{10}$FHB index using a simple linear regression procedure (SAS, version 9·1).

Results

When individual crops grown 1 year before the sampling year were tested, wheat was significantly different from soybean-pea, and fallow. There were neither significant differences in $\log_{10}$CN level between wheat, canola and flax, nor between canola, soybean-pea, flax and fallow (Table 2). When all crops except for wheat were grouped together, there was no significant difference in $\log_{10}$CN levels between wheat and the grouped crops. However, when wheat and canola were assigned to one group, and other crops to a second group, $\log_{10}$CN values were significantly different (Table 2). Therefore, the average $\log_{10}$CN values for wheat-canola and for all other crops were used for weighting the effects of crops grown 1 year before on $\log_{10}$CN.

When CN levels between individual crops grown 2 years before the sampling year were similarly tested, there were significant differences between wheat, soybean-pea, flax and fallow, and between canola, flax and fallow. There were no differences between wheat and canola, and between flax and fallow (Table 2). When the $\log_{10}$CN values for each crop were grouped and averaged, the wheat value was significantly higher than the average for canola-soybean-pea, which was significantly higher than the average of flax-fallow. When all crops except for wheat were grouped together, the $\log_{10}$CN level for wheat was significantly higher than the average for the other crops. When wheat and canola were grouped together, the average $\log_{10}$CN level was significantly higher than the average value for all the other crops. Therefore, three different crop combinations of $\log_{10}$CN values were considered for weighting the effects on crops grown 2 years before on $\log_{10}$CN.

When $\log_{10}$CN levels between individual crops grown 3 years before the sampling year were tested, the wheat value was significantly less than the canola value, but there were neither significant differences between wheat and other crops nor between canola and other crops (Table 2). When all crops were grouped except for wheat, the wheat $\log_{10}$CN level was significantly less than the other crops. There was no significant difference between the average $\log_{10}$CN for wheat-canola and the average $\log_{10}$CN for the other crops (Table 2). The effects of crops grown 3 years before did not exhibit significant effects on $\log_{10}$CN and, therefore, were not considered in the crop effect weightings.

In regards to tillage effects, there was no significant difference in the average $\log_{10}$CN values between zero and

Table 3 Logarithm of the numbers of *Fusarium graminearum* colonies on various crop stubbles per square metre of soil for different tillage systems

Tillage	Mean $\log_{10}$CN[a]	Tillage	Mean $\log_{10}$CN
Zero tillage	3·62 a	Zero/minimum tillage	3·60 a
Minimum tillage	3·59 a	Conventional tillage	3·34 b
Conventional tillage	3·34 b		

[a] Mean base-10 logarithm of the numbers of *F. graminearum* colonies per square meter ($\log_{10}$CN). Differences in $\log_{10}$CN between crops were tested using the *t* test in the Fisher's least significant difference (LSD) procedure ($P < 0·0001$) (SAS, version 9·1).

Different letters indicate significant difference between tillage types in $\log_{10}$CN.

minimum tillage. However, the average zero-minimum tillage $\log_{10}$CN value was significantly higher than that for conventional tillage (Table 3). The average $\log_{10}$CN of the zero-minimum tillage fields and the conventional tillage fields were considered for weighting the effects of tillage on the $\log_{10}$CN value.

The average $\log_{10}$CN value for crops grown 1 year before was 1·1 times greater than the average $\log_{10}$CN value for crops grown 2 years before. Thus, the year weightings for crops grown 1 and 2 years previous were assigned values of 1·10 and 1·00, respectively.

Three different rotation scenarios were evaluated for development of a CPI model (Table 4). Weighted $\log_{10}$CN values ($\log_{10}$CN value for a crop or group of crops in a rotation scenario divided by the smallest $\log_{10}$CN value in the same scenario and multiplied by the corresponding year score) for each crop or group of crops is shown in Table 4. The weighted value for wheat-canola in rotation scenario 1, for example, was calculated as 1·27 = 3·62 × 1·10/3·12 (Table 2). The score for zero-minimum tillage systems was expressed as their average $\log_{10}$CN value divided by the mean $\log_{10}$CN value for conventional tillage fields (1·08 = 3·60/3·34) (Table 4).

Table 4 Mean base-10 logarithm of the numbers of *Fusarium graminearum* colonies per square metre ($\log_{10}$CN) of soil for different crops and tillage systems

		Rotation	Score[b]
Scenario 1[a]	1 year before	Wheat/Canola	1·27
		Others	1·19
	2 years before	Wheat	1·15
		Canola/Soybean/Pea	1·09
		Flax/Fallow	1·00
Scenario 2	1 year before	Wheat/Canola	1·20
		Others	1·12
	2 years before	Wheat	1·09
		Others	1·00
Scenario 3	1 year before	Wheat/Canola	1·24
		Others	1·16
	2 years before	Wheat/Canola	1·12
		Others	1·00
Tillage		Zero/Minimum tillage	1·08
		Conventional tillage	1·00

[a] Three scenarios for crop combinations were based on significant differences in base-10 logarithm of CN values among the crops in the previous 2 years.

[b] A crop score was expressed as $\log_{10}$CN for this crop divided by that of the lowest $\log_{10}$CN value and multiplied by the corresponding year score (1·10). A tillage score was expressed as the mean $\log_{10}$CN for zero and minimum tillage and divided by that of conventional tillage.

Three CPI models were developed based on the weighted $\log_{10}$CN values from Table 4 for various crops in each rotation scenario, tillage, their interactions and their squared values (Table 5). The step-wise regression models for rotation scenarios 1 and 2 selected very similar independent factors. The interaction of crops grown 1 and 2 years before and tillage was squared in scenario 2 but not in scenario 1. The interaction of crop grown 2 years before and tillage was squared in both scenarios. The stepwise regression model for scenario 3, selected the squared value for crop grown 1 year before and tillage, as well as tillage. The CPI model with the highest R^2 value (0·933) was that for rotation scenario 2 (Table 5). The VIF value for the two factors, $(C_2 \times C_1 \times T)^2$ and $(C_2 \times T)^2$, was <10, indicating that multicollinearity was not significant and, therefore, the CPI model for rotation scenario 2 was statistically valid.

The CPI model was tested using the actual data that were collected in seven fields in 2006 (Table 6). The root mean square error for the predicted CPI was 0·14 and the mean bias error was slightly positive at 0·07.

The CPI model was also evaluated using the jack-knife full cross-validation method (Walker, 2007). The R^2 value for prediction of $\log_{10}$CN logarithm was 0·899 (Fig. 1). The slope value for the regression was close to 1. The CPI model, using crop rotation and tillage practices in the 2 years prior to the current crop, accounted for almost 90% of the variation in *F. graminearum* inoculum levels in the crop stubble of the crop monitored in 2006.

There was a significant relationship between CPI and FHB index ($R^2 = 0{\cdot}715$, $P < 0{\cdot}0001$) as shown in Fig. 2. There were overlapped data points in the figure; therefore some single data points could include more than one set of data.

Discussion

This is the first study to quantify previous year cropping practices according to cumulative *F. graminearum* inoculum levels on wheat stubble from the soil surface. A regression model was developed for the quantified cropping practices using a cropping practice index

Table 5 Regression models developed for base-10 logarithm of CN values (*Fusarium graminearum* colonies per square metre) in the three scenarios for crop combinations in the previous 2 years

	Model[a]	R^2	VIF[b]
Scenario 1	$\text{Log}_{10}\text{CN} = 0{\cdot}92413 + 1{\cdot}29901 C_2 \times C_1 \times T + 0{\cdot}47880\,(C_2 \times T)^2$	0·828	
Scenario 2	$\text{Log}_{10}\text{CN} = 1{\cdot}98423 + 0{\cdot}55975\,(C_2 \times C_1 \times T)^2 + 0{\cdot}4390\,(C_2 \times T)^2$	0·933	5·0
Scenario 3	$\text{Log}_{10}\text{CN} = 0{\cdot}98539 + 0{\cdot}94807\,(C_1 \times T)^2 + 0{\cdot}90830 T$	0·923	

[a] Models for $\log_{10}$CN were developed based on the three scenarios for crop combinations in the previous 2 years. C_1, C_2 and T represent crops grown 1 year before, 2 years before, and tillage employed in the previous 2 years.

[b] VIF represented variance inflation factors (Longnecker & Ott, 2004).

Table 6 The actual and predicted cropping practice index (CPI) values for the model from data collected from seven fields in 2006

	Field 52[a]	Field 53	Field 54	Field 55	Field 56	Field 57	Field 58
Actual CPI[b]	3·32	3·29	3·67	3·24	3·27	3·66	3·28
Predicted CPI[c]	3·46	3·46	3·57	3·23	3·46	3·57	3·44

[a] Information on crop rotation and tillage for Fields 52, 53, 54, 55, 56, 57 and 58 is showed in Table 1.

[b] Actual CPI values were obtained from base-10 logarithm of *Fusarium graminearum* colonies per square metre ($\log_{10}$CN).

[c] CPI values were predicted using the CPI model: CPI = 1·98423 + 0·55975 $(C_2 \times C_1 \times T)^2$ + 0·4390 $(C_2 \times T)^2$, which was developed based on the cropping practices used in scenario 2 (see Table 4). R^2 value for the regression of actual and predicted CPI was 0·567 ($P < 0·0001$).

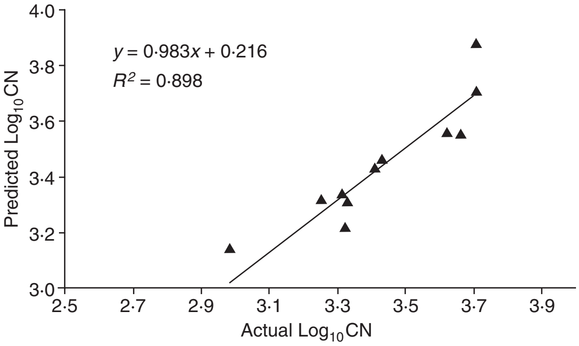

Figure 1 Jack-knife full cross-validation of the cropping practice index (CPI) model for rotation scenario 2 (Table 4), in which wheat or canola was assigned score 1·20, and other crops were 1·12 for the first year; wheat was assigned 1·09 and others were 1·00 for the second year. In the regression model, CN represents *Fusarium graminearum* colonies per m^2, variables *x* and *y* indicate actual and predicted $\log_{10}$CN, respectively.

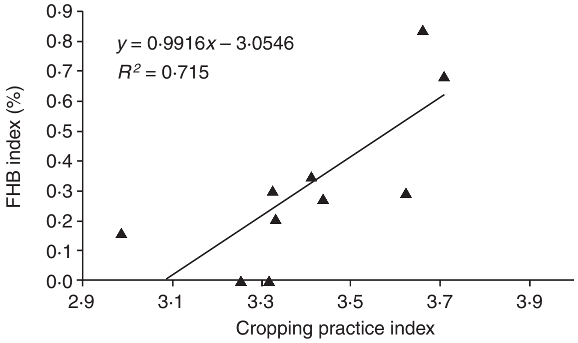

Figure 2 Relationship between logarithm of fusarium head blight (FHB) index and cropping practice index (CPI) calculated with the prediction model, $\log_{10}\text{CN} = 1·98423 + 0·55975 (C_2 \times C_1 \times T)^2 + 0·4390 (C_2 \times T)^2$ in the scenario 2 (Table 4). In the regression model, variables *x* and *y* indicate CPI and FHB index, respectively.

derived from the various rotation scenarios. Prediction accuracy for the CPI model was approximately 90% based on the jack-knife full cross-validation method (Walker, 2007). The model was also used successfully to predict CPI values for an independent year and was strongly correlated to FHB index.

Cropping practices were quantified based on the significant effects of the preceding crops on fusarium inoculum level on various crop stubbles on the soil surface in this study. Wheat and canola crops played more important roles in accumulation of inoculum than other crops (Table 2). Rotation of wheat with non-host crops, such as clover, alfalfa, potato and soybean, reduces the amount of infested wheat stubble and FHB (Sutton, 1982; Teich & Nelson, 1984; Windels & Kommedahl, 1984; Parry *et al.*, 1995). This study demonstrated that canola grown in the previous 2 years showed no difference from wheat in its effect on fusarium inoculum level, which could be associated with canola's capability of harbouring *F. graminearum* (Chongo *et al.*, 2001).

Tillage was another important factor in quantifying cropping practices. Zero or minimum tillage contributed significantly more to fusarium inoculum level than conventional tillage (Table 3). The effect of tillage on wheat stubble and pathogen survival has been well documented. *Fusarium* pathogens can survive on stubble and wheat kernels on the soil surface (zero or minimum tillage) for more than 2 years (Inch & Gilbert, 2003; Pereyra *et al.*, 2004). This study found that conventional tillage made a significant reduction in fusarium inoculum levels (Table 3). Wheat stubble partly decomposes and approximately 30% of dry matter stubble is left after 24 months in the soil (Parry *et al.*, 1995; Pereyra *et al.*, 2004). There was no significant difference between zero and minimum tillage systems in this study. Both zero tillage and minimum tillage leave large amounts of crop stubble on the soil surface. Because *G. zeae* requires light to form perithecia (Inch & Gilbert, 2003), this condition could be satisfied only for stubble remaining on the soil surface. Therefore, zero and minimum tillage can build up a larger reservoir of *G. zeae* perithecia compared to conventional tillage.

The CPI model, developed using cropping practice factors, indicated that fusarium inoculum level increased when wheat and canola crops were grown in the previous 2 years and when more zero or minimum tillage was employed in the previous 2 years.

A significant relationship between CPI and FHB index was found in this study; however, there are other factors affecting FHB index. The CPI value reflected the level of *F. graminearum* colonies on crop stubble from the soil surface only and not the *G. zeae* perithecial level or the airborne-inoculum level. *Gibberella zeae* perithecial formation occurs over a long time period from the early spring to the late summer in Canada (Inch & Gilbert, 2003), and needs appropriate temperature, moisture and light conditions (Sutton, 1982; Inch & Gilbert, 2003). This is affected by more than just the cropping practices. *Gibberella zeae* ascospore dispersal occurs throughout the same period as the perithecial formation (Fernando *et al.*, 2000; Inch *et al.*, 2005), and only spores discharged at the wheat flowering stage are real inoculum (Wilcoxson *et al.*, 1992; Groth *et al.*, 1999). Weather conditions during this period control spore release (Sutton, 1982). The CPI model was developed to quantify the effects of cropping practices employed before the current year, which cause potential changes in fusarium inoculum levels. CPI can be coupled with the number of ascospores dispersed at the flowering stage to improve the reliability of the CPI as a predictor of FHB index.

The CPI model excluded the factor of cultivars used in the current years, as they had no effects on the fusarium inoculum levels on the crop stubble. There are some limitations for the CPI model. For example, it did not take into account fusarium resistance or susceptibility of crop cultivars because there were a limited number of fields in the study. However, the CPI model could be improved with additional sampling of fields and by including a fusarium susceptibility factor.

Importantly, the CPI score developed in this study can be integrated into a broader disease management strategy. It can be used with weather conditions for prediction of *F. graminearum* airborne inoculum level, fusarium head blight disease and mycotoxins produced by the pathogen. This application will be reported in a separate paper.

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