Interactive effects of foliar diseases and fungicide sprays in cultivars of winter wheat in Ontario

J.C. Sutton and G. Roke[1]

Foliar diseases were monitored and yields were estimated in five cultivars of winter wheat grown in field plots and sprayed or not sprayed with propiconazole (Tilt). Septoria tritici blotch and septaria nodorum blotch progressed collectively at similar rates among the tested cultivars. Ranking of the cultivars in descending order of powdery mildew intensity was Favor, Augusta, Fredrick and Frankenmuth, and Houser. The virulence formula of the race *Erysiphe graminis* var. *tritici* isolated from the plots was 1,2,3a,3b,4,5/Ma,3c. Progress of leaf rust was most rapid in Favor, moderately rapid in Fredrick but slow in Frankenmuth, Houser and Augusta. The septoria blotches became moderately severe on the upper leaves and spikes only when leaf rust or powdery mildew were mild or absent. Tan spot progressed in all cultivars, mainly before anthesis. Propiconazole managed all foliar diseases effectively except for chlorosis and necrosis of unknown etiology. The fungicide significantly increased grain yields of all cultivars except Fredrick.

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On a surveillé les maladies foliaires et évalué les rendements de cinq cultivars de blé d'hiver dans des parcelles traitbes et non traitbes avec du propiconazole (Tilt). La tache septorienne *(Septoria tritici)* et la tache des glumes (*S. nodorum)* se sont développées au même rythme parmi les cultivars traitbs. Le classement des cultivars par ordre dbcroissant d'intensité du blanc est le suivant: Favor, Augusta, Fredrick et Frankenmuth et Houser. La formule de virulence de la race d'*Erysiphe graminis* var. *tritici* isolée des parcelles était 1,2,3a,3b,4,5/Ma,3c. La progression de la rouille des feuilles s'est avérée rapide chez Favor, modbrbment rapide chez Fredrick et lente chez Frankenmuth, Houser et Augusta. Les taches septoriennes sont devenues plus ou moins importantes sur les feuilles supbrieures et les glumes, seulement lorsque la rouille des feuilles et le blanc btaient faibles ou absents. *Pyrenophora trichostoma* s'est développé chez tous les cultivars principalement avant l'anthèse. Le propiconazole a assure une gestion efficace de toutes les maladies foliaires, exception faite des chloroses et necroses d'origine inconnue. Le fongicide a permis une augmentation significative des rendements en grain de tous les cultivars sauf Fredrick.

introduction

New cultivars of soft-white winter wheat (Favor, Frankenmuth, Augusta and Houser) were introduced into Ontario agriculture in 1980-83. The introduction coincided with a surge of interest in the province in intensive management of winter wheat, particularly the use of fungicides for managing foliar diseases. Foliar fungicides have improved productivity of winter wheat in some growing seasons in Ontario (Sutton 1985) but the extent of yield promotion was a function of the cultivar (Sutton and Roke 1984). Overall disease reactions of the new cultivars have been recorded in routine variety trials but patterns and rates of disease progress and comparative responses of the cultivars to foliar fungicides have not been reported. Because of the potential importance of these variables in disease management, we monitored diseases and examined responses to fungicides of the new cultivars and of Fredrick, the principal cultivar grown in recent years.

Materials and methods

Winter wheat cultivars were grown in plots (1.3× 3.0m) arranged in a randomized complete block design at the Elora Research Station near Guelph, Ontario in 1982-83 and 1983-84). Two plots of each cultivar, one sprayed with fungicide and the other unsprayed, were included in each block. Cultivars Augusta, Favor, Fredrick and Houser were grown in both years and Frankenmuth also was grown in 1983-84. The seed was treated with Vitaflo 250 (carbathiin, Uniroyal Inc.) and sown on 17 September 1982 and 15 September in 1983. In both growing seasons the wheat followed red clover in the crop sequence and received 80 kg N (ammonium nitrate) in mid-April. The fungicide product Tilt 250 EC (propiconazole, Ciba-Geigy Canada Ltd) was applied to the wheat at a dose of 125 g a.i. in 300 L water/ha using an air-pressurized backpack sprayer equipped with four hollow-cone D2-13 nozzles and operated at 200 kPa. In 1983, Tilt was applied on 13 and 27 May and 27 June when the wheat was at growth stages (GS) 25-29, 31-32 and 55-60 (Zadoks *et al.* 1974). In 1984, Tilt was applied once on 21 June (GS 69).

Disease on the leaves and spikes was assessed using the scale of Horsfall and Barratt (discussed in Horsfall and Cowling 1978). Assessments were conducted at about weekly intervals beginning 24 May in 1983 and 13 June in 1984. Total disease and senescence was assessed by estimating the percent area discolored and the approximate severity of individual diseases on the assessed leaves was noted. Septoria tritici blotch and septoria nodorum blotch were assessed collectively by estimating the percent leaf area bearing pycnidia of the respective causal pathogens, *Mycosphaerella graminicola* (Fuckel) Schroeter and *Leptosphaeria nodorum* Miller. In 1984, powdery mildew, caused by *Erysiphe graminis* DC. ex Merat f. sp. *tritici* Em. Marchal was assessed on 13 June. One isolate of the pathogen was obtained from each cultivar and characterized with respect to race using the methods of Bailey and MacNeill (1983).

[1] *Department of Environmental Biology, University of Guelph, Guelph, Ontario N1G 2W1.*

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To assess yield and yield components in 1983, the number of spikes/m^2 were counted, total grain yield was obtained using a small-plot combine harvester and 1000-kernel weights were estimated. In 1984, 1000-kernel weights were determined for hand-harvested grain. Grain yields were expressed based on 14.8% moisture content.

After each time of sampling, the four plot means for each treatment were analysed by standard analysis of variance and overall treatment means were compared using Duncan's new multiple range test (Steel and Torrie 1980). In 1984 the treatment means were transformed for analysis, using the arcsin transformation. Apparent infection rates (r) were computed from plot means according to the formula (Zadoks and Schein 1979).

$$r = (\text{logit } x_2 - \text{logit } x_1)/(t_2 - t_1)$$

Results

1983. The principal diseases on the wheat foliage were septoria tritici blotch, septoria nodorum blotch and tan spot. Tan spot, caused by Pyrenophora *trichostoma* (Fr.) Fckl., developed mainly at GS 25-28 (mid-May to mid-June) while the septoria blotches (especially septoria tritici blotch) progressed chiefly at GS 25-85 (mid-May to mid-July).

With certain exceptions, disease progressed at similar rates in all cultivars tested. Discoloration of the foliage, associated mainly with disease and senescence, was similar among the various cultivars (unsprayed) in June, but was significantly more extensive in Fredrick than the other cultivars in July (Table 1). Intensities of pycnidia of *M. graminicola* and *L. nodorum* were higher in Houser than in other cultivars when estimated on 7, 21 and 28 June but not on the flag leaf later in the growing season (Table 2). However, r values calculated for progressive increases in pycnidial intensities on the third or fourth leaves in the periods of 14-28 June, 14 June-5 July and 21 June-5 July did not differ significantly among cultivars and ranged from 0.17 to 0.26. Few pycnidia developed on the flag leaves.

Foliar diseases usually were much less intense when Tilt was applied than in the untreated wheat. Tilt reduced foliar discoloration assessed in cultivar Augusta on 21 June, in all cultivars on 28 June, and in Augusta, Favor (leaf 1 only) and Houser, but not Fredrick, on 12 July (Table 1). Tilt applied on 13 or 27 May failed to reduce estimated discoloration of leaves 6, 5 and 4 variously assessed on 24 and 31 May and 7 June. However, the fungicide markedly restricted areas bearing pycnidia of the septoria blotch pathogens when assessed on leaves 6 to 1 at various times in the period of 24 May to 19 July (Table 2). In most instances few or no pycnidia were evident in any cultivar.

Table 1. Disease progress, and effects of Tilt on disease progress, in four cultivars of winter wheat at Elora in 1983.

Cultivar	Tilt applied[+]	Estimated % leaf area discolored: 21 June Leaf 3	28 June Leaf 2	12 July Leaf 2	12 July Leaf 1
Augusta	–	41 b[++]	23 bc	88 de	30 cd
	+	23 a	15 a	74 bc	15 ab
Favor	–	40 b	49 e	80 cd	49 e
	+	45 b	40 de	89 def	31 d
Fredrick	–	45 b	32 cd	98 f	68 f
	+	44 b	18 ab	97 ef	67 f
Houser	–	44 b	25 bc	84 d	24 bcd
	+	22 a	12 a	60 a	10 a

[+] Tilt was applied on 13 and 27 May. and 22 June.
[++] Numbers in a column followed by the same letter are not significantly different (P = 0.05, Duncan's new multiple range test).

Table 2. Progress of septoria tritici blotch and septoria nodorum blotch, and effects of Tilt on disease progress, in four cultivars of winter wheat at Elora in 1983.

Cultivar	Tilt applied[+]	Estimated % leaf area with pycnidia: 24 May Leaf 6	7 June Leaf 5	21 June Leaf 4	28 June Leaf 3	5 July Leaf 2	19 July Leaf 1
Augusta	–	24 bc[++]	22 bc	17 c	20 b	15 c	0.8 ab
	+	4 a	1 a	0 a	0 a	0 a	0.3 a
Favor	–	24 bc	24 c	16 c	23 b	10 b	2.1 c
	+	5 a	4 a	0 a	0 a	1 a	0.9 ab
Fredrick	–	19 b	14 b	12 bc	15 b	8 b	0.3 a
	+	3 a	0 a	0 a	0 a	0 a	0.2 a
Houser	–	28 b	29 c	23 d	34 c	9 b	1.2 b
	+	7 a	1 a	0 a	0 a	0 a	0.8 ab

[+] Tilt was applied on 13 and 27 May, and 22 June.
[++] Numbers in a column followed by the same letter are not significantly different (P = 0.05, Duncan's new multiple range test).

Table 3. Comparative progress of disease, estimated as discoloration of the leaves and spikes, in five cultivars of winter wheat at Elora in 1984.

Cultivar	Estimated % discoloration'						
	20 June	30 June		7 July		13 July	19 July
	Leaf 3++	Leaf 2	Leaf 3	Leaf 1	Leaf 2	Leaf 1	Spike
Augusta	30 b*	8 a	69 ab	6 a	56 c	21 c	14 b
Favor	28 b	25 b	57 bc	60 c	92 b	72 a	30 a
Frankenmuth	15 a	3 a	26 d	9 ab	51 a	31 b	16 b
Fredrick	54 c	10 a	73 a	12 ab	88 b	38 b	16 b
Houser	15 a	4 a	26 d	10 ab	67 c	33 b	9 c

+ Data were detransformed from arcsin-transformed values.
++ Leaves 1 to 3 were the flag, penultimate and third leaves, respectively.
* Values in a column followed by the same letter are not significantly different (P = 0.05, Duncan's new multiple range test).

Tilt significantly promoted yield of Augusta by 13% to 7.9 t/ha, of Favor by 14% to 6.4 t/ha, and of Houser by 17% to 7.7 t/ha. The grain yield of Fredrick was 6.4 t/ha and not increased by Tilt. Yields of sprayed Augusta and Houser were significantly higher than those of sprayed Favor and Fredrick. Thousand kernel weights were not increased significantly in any cultivar. Numbers of spikes/m^2 were 4 to 100% higher in the sprayed than unsprayed wheat.

1984. Powdery mildew, leaf rust caused by *Puccinia recondita* Rob. ex. Desm. f.sp. *tritici,* septoria tritici blotch, septoria nodorum blotch, tan spot and leaf chlorosis and necrosis of unknown etiology were observed in the wheat. Tan spot was confined to the lower half of the canopy and progressed mainly before anthesis. Powdery mildew was first observed at late tillering (GS 26-29) and continued to progress in Augusta and Fredrick until the upper canopy senesced. Rust and the septoria blotches became intense in the upper canopy of some cultivars after anthesis.

Patterns were evident in the ranking of the cultivars with respect to discoloration of the upper three leaves (Table 3). Discoloration usually was relatively severe in Favor and Fredrick, mild in Houser and Frankenmuth, and variously mild to severe in Augusta. Discoloration of Favor was chiefly associated with severe leaf rust, but powdery mildew was severe on leaf 3 and chlorotic flecking affected leaves 2 and 1. Fredrick was affected severely by powdery mildew (leaves 3 and 2), leaf rust (leaf 1) and chlorotic flecking (leaves 3, 2 and 1), but mildly by the septoria blotches. Thrips (Thripidae) completely discolored some flag leaves of Fredrick but not other cultivars. Powdery mildew and the septoria blotches were the main diseases on Augusta, but traces of leaf rust were also observed. Mild leaf rust and septoria blotches developed on Frankenmuth and Houser.

Disease on the spikes differed substantially among the cultivars (Table 3). Powdery mildew was severe on Augusta but not in the other cultivars. Leaf rust was severe on spikes of Favor, moderately severe in Fredrick, but only traces were observed in Augusta, Frankenmuth and Houser. Septoria nodorum blotch was moderately severe on the spikes of Frankenmuth, Fredrick and Houser but only traces of the disease were evident in Augusta and Favor.

Table 4. Intensity of powdery mildew in five cultivars of winter wheat estimated on 13 June 1984 at Elora.

Cultivar	Growth Stage	Powdery Mildew (%)+
Augusta	54-57	41c++
Favor	56-67	66d
Frankenmuth	56-57	19 b
Frcdrick	56-57	27 b
Houser	56-57	3 a

+ Estimated area of leaf 4 with powdery mildew. Data were detransformed from arcsin-transformed values.
Numbers in a column followed by the same letter are not significantly different (P = 0.05 Duncan's new multiple range test).

Wide differences in susceptibility among the cultivars to powdery mildew were evident in assessments of leaf 4 (Table 4). Favor was the most susceptible but Augusta also was severely diseased. Little powdery mildew developed on Houser. Frankenmuth and Fredrick were of intermediate susceptibility. The same ranking was obtained when powdery mildew was estimated on the sheaths of the lower leaves. Isolates of *E. graminis* var. *tritici* from the cultivars revealed only one race of the pathogen. The virulence formula of this race was 1, 2, 3a, 3b, 4, 5/Ma, 3c. This race overcomes resistance genes Pm Ma, Pm 3c.

Tilt applied on 21 June markedly suppressed all of the diseases, except chlorotic flecking, observed in the upper canopy, as exemplified by data for the flag leaf (Table 5). The suppression was significant as late as 19 July. Moderately severe leaf rust was observed on leaves 1 and 2 of treated Favor on 13 and 19 July.

Severe storms on 5 July caused substantial lodging of the wheat. Lodging was estimated in each plot on a scale of 10 equal increments from 0% to 100%. Lodging of unsprayed and

Table 5. Effects of Tilt[+] on disease and senescence in the flag leaf of various cultivars of winter wheat at Elora in 1984.

Date	Tilt	Estimated flag leaf discoloration (%)[++] in the following cultivars: Augusta	Favor	Frankenmuth	Fredrick	Houser	Combined**
7 July	–	6 b*	60 b	9 b	12 b	10 b	–
	+	0 a	2 a	0 a	0 a	0 a	–
13 July	–	21	72	31	38	33	76
	+	–	–	–	–	–	5 b
19 July	–	100 b	100 b	100 b	100 b	100 b	–
	+	79 a	98 a	74 a	97 a	98 a	–

[+] Tilt was applied on 21 June.
[++] Data were detransformed from arcsin-transformed values.
* Values in a column for a given sampling date and followed by the same letter are not significantly different (P = 0.05, Duncan's new multiple range test).
** Combined data for all cultivars.

Table 6. Yield response of five winter wheat cultivars to a single application of Tilt at Elora in 1984.

Fungicide Spray	1000-kernel wt (g)[+] of the following cultivars: Augusta	Favor	Frankenmuth	Fredrick	Houser
Check	33.6 a[++]	34.9 a	34.6 a	38.3 a	34.6 a
Tilt	38.1 b	36.1 a	37.6 b	37.9 a	37.8 b

[+] Adjusted to 14.8% moisture content.
[++] Numbers in a column followed by the same letter are not significantly different (P = 0.05, Duncan's new multiple range test).

sprayed wheat of individual cultivars did not differ significantly, and averaged as follows: Favor 65%, Augusta 40%. Fredrick 25%. Frankenmuth 22% and Houser 4%.

Tilt significantly promoted yields, estimated as 1000-kernel weights, in Augusta, Frankenmuth and Houser but not in Favor or Fredrick (Table 6). Yield promotion was greater in Augusta (13.4%) than in Houser (9.2%) or Frankenmuth (8.6%).

Discussion

The epidemic patterns of the foliar diseases, especially powdery mildew and leaf rust, varied widely among the winter wheat cultivars. Observations in 1984 of severe powdery mildew on leaf 5 and, later, the spikes of Augusta wheat underscored the potential in this cultivar for mildew epidemics of long duration. Favor showed high susceptibility to powdery mildew in the lower canopy before anthesis and to leaf rust in the upper canopy after anthesis. Rapid development of leaf rust may have precluded progress of powdery mildew in the uppper canopy. Frankenmuth ranked closely to Fredrick in exhibiting moderate resistance to powdery mildew when assessed on 13 June but later showed less mildew than Fredrick. Resistance of Frankenmuth to leaf rust was intermediate to the moderately resistant Fredrick and the highly resistant Augusta. Houser showed remarkably strong resistance to the identified race of *E. graminis* var. *tritici* and high resistance to the prevalent races of leaf rust. The leaf chlorosis and necrosis observed mainly in Fredrick and Favor warrant study to determine the etiology of these symptoms.

Observations in 1983 indicated that tan spot and the septoria blotches progressed at similar rates in the various cultivars. Leaf discoloration associated with all three diseases increased at similar rates before mid-June, while after mid-June, r-values for pycnidial intensities of M. *graminicola* and L. nodorum were not significantly different among the cultivars. Significantly higher pycnidial intensities in Houser than in other cultivars during June possibly arose from earlier initiation, or rapid initial progress, of epidemics of the septoria blotches in this cultivar.

Disease patterns on the upper leaves and spikes of the various cultivars in 1984 pointed to possible disease interactions. The septoria blotches progressed to moderately intense levels only when leaf rust and powdery mildew were mild or absent. Intensities of the septoria blotches were low on leaves and spikes of Favor, in which leaf rust was severe, and on the leaves of Fredrick, in which leaf rust and powdery mildew were well-developed. Spikes of Augusta bearing substantial powdery mildew showed only trace amounts of septoria nodorum blotch. On the other hand, septoria nodorum blotch developed substantially on spikes of Frankenmuth and Houser

where not more than traces of rust and mildew were observed. Precolonization of wheat tissues by the biotrophic pathogens apparently restricted or precluded colonization by the necrotrophs.

Tilt was highly effective for managing the various foliar diseases except for the chlorosis and necrosis of unknown etiology, as was found in earlier studies (Sutton 1985). In 1983, the sequence of three applications, with the final spray on 22 June, protected the wheat effectively against the septoria blotches until the upper leaves and spikes senesced 3 to 4 weeks later. In 1984, the single spray of 21 June protected all cultivars until senescence except Favor. The development of leaf rust on Favor about 2 to 3 weeks after Tilt was applied probably was related to rapid multiplication of the pathogen (high R Zadoks and Schein 1979), as observed in other susceptible cultivars (Shaner and Hess 1978). Epidemic rates of leaf rust also may accelerate rapidly when residual activity of the fungicide declines (Sutton and Steele 1983).

Tilt significantly increased yields of all cultivars except Fredrick. The fungicide increased yields of Augusta, Frankenmuth and Houser both in 1983 and 1984, and of Favor in 1983. Increase in total grain yield in 1983 was related to numbers of spikes/m^2 but not to increased 1000-kernel weights. Sparsity of rainfall and high temperatures severely stressed the wheat after anthesis in 1983 and probably restricted grain filling. The failure of Tilt to promote yield of Favor in 1984 probably was related to the severe lodging of this cultivar.

The diverse patterns of disease and yield responses to Tilt observed in the various cultivars provide some rationale for fungicide use. The value of fungicide usage clearly was related to the cultivar. The poor yield responses of Fredrick supported earlier conclusions (Sutton and Roke 1984) that fungicide sprays may not be justified in this cultivar. Sprays targeted against powdery mildew are more likely to be justified in Augusta and Favor than in more resistant cultivars. Fungicide timed at anthesis (Sutton 1985) may be warranted in responsive cultivars susceptible to the septoria blotches or leaf rust. The economic benefits of the anthesis spray, however, may depend heavily on weather affecting disease and crop during the grain-filling period.

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