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A Disease Management Response to the Introduction of Wheat Stripe Rust to New Zealand

New Zealand agriculture has been dominated by animal production for many years, but an important cropping industry occupies approximately 1% of the total farmland. Wheat has become a significant constituent of crop production, supplying most of the local requirements for flour, although a small amount of high-quality wheat is imported from Australia most years. During the late 1970s, wheat occupied about 100,000 ha (250,000 acres) and was the major grain crop in the country. Wheat is grown mostly in mixed cropping enterprises, such as those found in the area around Lincoln University College (Fig. 1).

Many crop pathogens important in other parts of the world are not present in New Zealand because of its isolation from other landmasses and relatively recent colonization and because major agricultural development based on nonindigenous crops has occurred only within the past 80 years. Even though many pathogens were introduced with new crop species and cultivars, and new pathogens and pathogen races have arrived subsequently, a number of major pathogens are still absent.

Until 1979, the causal agent of wheat stripe rust (*Puccinia striiformis* West.) was not present in Australasia. In October 1979, plants infected with stripe rust were found in several locations in Victoria and New South Wales, Australia, and the disease spread rapidly throughout the major wheat-growing regions. In November 1980, the disease was observed in the southern region of the South Island of New Zealand. This was not unexpected, because there has been a history of pathogen and pest transfer across the Tasman Sea from Australia to New Zealand; under certain atmospheric conditions, soil particles and bush fire debris from Australia are deposited in New Zealand. The pathogen spread rapidly throughout the wheat production areas in the South Island and then to the North Island. By 1981, the disease was present in most wheat crops and became of great concern to all associated with the wheat industry.

This paper describes the reaction to the new disease problem and the philosophy

Fig. 1. The Canterbury Plains area in the South Island of New Zealand, where wheat is grown in mixed sheep/crop production enterprises.

and development of a disease management program to minimize the impact of the disease by means of available technology, supported when necessary by specific research investigations.

Initial Status and Reactions

During the first season after rust introduction, several groups made an intensive effort to define the new problem and establish research priorities. The pathogen was identified as race 104 E137, which induced susceptible reactions (Fig. 2) on the dominant cultivars grown in New Zealand (Table 1). Tests at the Plant Breeding Institute in Cambridge, England, confirmed the race identification and indicated that most released and test cultivars were susceptible but that a few breeding lines were resistant.

At the time of pathogen introduction, 60% of wheat seed was treated with triadimenol/fuberidazole (Baytan F17) to protect against other pathogens. The remaining 40% was treated with either carboxin/thiram (Vitaflow) or captan (Orthocide). Triadimefon (Bayleton) was registered for use on cereals and was used to a limited extent on wheat for speckled leaf blotch and leaf rust control. The efficacy of the triazole chemicals for stripe rust control was confirmed during the first season, and sufficient quantities were airfreighted from Europe to meet a heavy demand from growers. Crops were sprayed at least once at rates recommended on the basis of European experience, and some received as many as five sprays.

The epidemic started early in crop growth (four- to five-leaf stage), continued until maturity, and caused yield losses of up to 50% on some cultivars, with an estimated average loss of 5–10%. Yield losses were associated with reduced grain number per ear and reduced grain weight.

At the end of the first season, a consensus of the best short-term strategy was developed. Consideration was given to cultural control, cultivar resistance, chemical control, and optimization of grower profits. Recommendations included: 1) selecting the wheat cultivar Oroua for crops with low yield potential (low-fertility soils for autumn-sown or all spring-sown crops) or the cultivars Rongotea, Kopara, and Takahe for crops with high yield potential, 2) treating all seed with Baytan, and 3) spraying crops with high yield potential with Bayleton "at first sight" of infection and thereafter "when it reappears." Many growers implemented these recommendations, although some preferred a scheduled program starting with a combined fungicide/herbicide spray at the five-leaf stage and repeated thereafter every 3–4 weeks until early grain filling. A withholding period of 49 days before harvest prevented spraying later than early grain filling.

Thus, wheat production became heavily reliant on chemical control by triazole fungicides (propiconazole [Tilt] received preliminary registration that season), with growers varying in interpretation of the recommendations. "At first sight" and "when it reappears" are subjective concepts, especially in relation to identifying initial infection, which occurred at low frequency on single plants (Fig. 3). The cultivar Kopara was not grown extensively because of susceptibility to speckled leaf blotch.

We decided a disease management plan was needed to optimize fungicide usage on the basis of disease levels and projected yield losses in individual fields. We therefore initiated a research program using the principles of integrated pest management.

Management System Requirements

Integrated pest management is the optimization of pest control in a sound ecological manner to maintain multiple pest populations below levels at which economic damage occurs. The development of a pest management program depends on knowledge or definition of: 1) the biology of the pests and crop, 2) reliable sampling techniques, 3) economic thresholds, and 4) control systems.

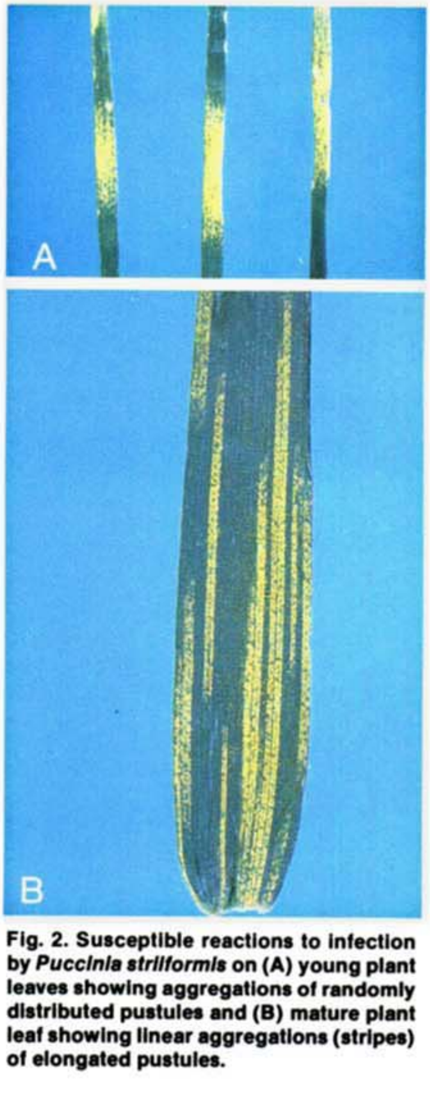

Fig. 2. Susceptible reactions to infection by *Puccinia striiformis* on (A) young plant leaves showing aggregations of randomly distributed pustules and (B) mature plant leaf showing linear aggregations (stripes) of elongated pustules.

The wheat production system in New Zealand during 1980 was such that stripe rust became the major pathogen. We decided, therefore, to develop a single management program that would allow incorporation of accepted control systems for diseases such as loose smut, take-all, and eyespot. In particular, seed treatments and rotations were based on the control requirements for these diseases. We assumed that production would be based on susceptible cultivars and that the stripe rust management program would be based on chemical control but would incorporate the current recommendations for reducing carryover of stripe rust inoculum by rotations and by removal of volunteer plants. A management program may be based on predicted disease progress or on disease monitoring relative to threshold levels. After considering the existing stripe rust prediction models, we adopted the latter approach because the observed disease severities could then be directly related to

Table 1. Reactions of commercial wheat cultivars to stripe rust, race 104 E137, and area sown in New Zealand during 1980–1981

Cultivar	Reaction	Area (ha)
Rongotea	Susceptible	21,000
Takahe	Very susceptible	19,000
Kopara	Moderately resistant	14,000
Karamu	Resistant	8,000
Hilgendorf	Very susceptible	7,500
Oroua	Resistant	7,400

Fig. 3. Plants in an initial focus of infection, with stripe rust symptoms.

experimentally determined threshold values for the same growth stage.

Implementation of a management program requires a rapid and reliable sampling plan that allows for classification of observed disease levels relative to defined thresholds. Sequential sampling is such a plan. Sampling intensity depends on the difference between the observed value and the defined threshold. When the observed value is much larger or smaller than the threshold, a decision is derived with a small sample. A larger sample is required when the observed value is closer to the threshold. Thus, sequential sampling provides for efficient sampling and considerable savings in time. We used knowledge gained from our research investigations (1) to define the sampling method, spatial pattern, and action levels required for developing a sequential sampling management plan.

Biology of Pathogen and Crop

The American and European literature (10) and local observations provided inputs on many aspects of the biology of both stripe rust and wheat. Urediniospores on volunteer plants were considered to be the major source of inoculum for initial infection of autumn-sown crops. Observed disease progress was consistent with information on temperature optima for infection (7–13 C) and development (10–18 C) and on leaf wetness (3 hours minimum, 8 hours optimum). Sporulation was inhibited during summer by high temperatures but systemic colonization continued, confirming that disease progress did not depend solely on new infections.

Information in the literaure on severity/yield loss relationships for crops in other countries was assumed to be invalid for the New Zealand production system, but information was available locally on the sensitivity of wheat crops to the presence of speckled leaf blotch and other diseases (3,15). We believe that an understanding of crop production constraints, derived from investigations of the physiology of yield potential and yield loss (2,14), is more likely to provide useful information on the reaction of a crop to a new pest problem than are empirical models of pest/crop relationships derived in other production areas. We therefore applied current knowledge and did further research on crop constraints to establish disease threshold levels for management purposes.

Sampling, Spatial Patterns, and Monitoring

Sampling of a portion of a population is commonly used to estimate the attributes of the total population. The sample unit defines the size and form of the sampled material, and the sample pattern defines the manner in which the sample units are arranged in the area studied (11,12). Sampling is used in integrated pest management to analyze the pest distribution, to assess pest frequency and/or severity, and to classify pest populations relative to predetermined thresholds. The sample unit and sampling pattern may be different for each of these purposes and should be chosen only after careful investigation of the pest population characteristics. The choice of sample unit and pattern may influence the sensitivity and reliability of estimation of incidence, or severity, and should be based on the observed distribution of the pest on plant organs.

Table 2. Sensitivity and reliability of four sampling methods for detecting stripe rust in commercial wheat fields

Sampling method	Incidence (%)[a] Mean[c]	Incidence (%)[a] SEM	Relative variability (%)[b] Mean	Relative variability (%)[b] SEM
"W" pattern				
100 × 10 tillers	13.0	6.1	11.3	1.1
10 × 100 tillers	4.4	1.9	39.7	6.5
Diagonal pattern				
100 × 10 tillers	4.2	2.1	28.4	10.3
10 × 100 tillers	4.4	1.9	39.6	11.4

[a] Measured on top three leaves.

[b] Calculated as standard error/mean sample incidence × 100.

[c] Mean values of 13 samples from four fields (3.5–12 ha) in the Lincoln area.

Table 3. Relationship between percentage incidence and percentage severity of stripe rust on top three leaves of wheat cultivar Rongotea in commercial fields and in field plots

Year	Site	Regression parameters and coefficients[a] Number of observations	Intercept	Slope	R^2
1981	Field plots	10	−0.06	0.03	0.86
1982	Fields	10	0.02	0.01	0.95
	Field plots	13	0.00	0.01	0.89
1983	Fields	45	−0.01	0.02	0.87
	Field plots	31	−0.01	0.02	0.75
Pooled data[b]		109	−0.01	0.02	0.75

[a] All regressions significant, $P<0.10$.

[b] Regression of combined incidence and severity values for all years and sites, since slope values of individual regressions not significantly different (17).

We tested the sensitivity and reliability of diagonal and "W" sampling patterns with two sample units, both based on pest incidence on the top three leaves. The results indicated (Table 2) that a "W" pattern with 100 10-tiller sample units along a drill row was appropriate for investigating the pest population frequency and distribution. The "W" pattern, when combined with a large number of relatively small sample units, is an example of a stratifed sampling system that is often more efficient than random sampling.

Analysis of spatial patterns is an essential component in developing a disease management program (13). Spatial patterns are described as random, aggregated, or uniform. A random pattern is one in which all sample units have an equal probability of containing the pest, whereas in an aggregated pattern, presence in one unit increases the chance of detecting the pest in nearby units. Uniform patterns are rigidly structured and usually are found only at high pest densities. Because the form of sample units, i.e., the part of the plant examined, may influence the observed spatial pattern, the sample units used in spatial pattern analysis must include the unit likely to be used in implementing the management program.

Statistical methods of fitting observed frequency distributions to theoretical models, dispersion indices, and methods describing the location and distance between pest occurrences have all been used to define spatial patterns (8,11). The fit of frequency distribution models is usually density-dependent, reflecting the change in population characteristics with time. This creates potential problems if the sampling system for management is based on frequency distributions. Frequency distribution models will not detect aggregation on a scale larger than that of the sample unit, creating further limitations on the interpretation (8). Several distribution models may be fitted to an observed population, and comparison of these analyses to other methods is necessary to provide a biologically meaningful assessment of pest distribution. This creates difficulties in implementing a pest management program based on regular monitoring because the pest density and its fit to a distribution model would have to be known before monitoring commenced.

Dispersion indices quantify the degree of aggregation rather than determine its presence or absence, as with frequency distribution analyses. The indices are generally less sensitive to the effects of population density and sample size and thus are more suited to the development of management systems. Spatial patterns are characterized by two factors: whether the basic unit of dispersion is an individual or an aggregate and whether the basic units are aggregated or distributed randomly (6). Frequency distributions and most dispersion indices do not distinguish between these two factors, but a method was developed (4,11) that recognized this duality of dispersion. In a regression of mean crowding on mean density, the slope value defines how the basic units are arranged with changes in pest density and the intercept describes whether the basic units are aggregates or individuals.

The spatial pattern of stripe rust in infected fields was analyzed by using a program to fit frequency distribution models and by calculating several dispersion indices. Techniques such as nearest neighbor and spatial autocorrelation, although representing the most detailed method of spatial analysis, were not used because of the high demand for labor resources to collect data.

The distribution of stripe rust infections on all sample units investigated was random at very low disease incidence and aggregated to varying degrees as incidence increased but became more random at incidences between 40 and 80% (1). At greater than 80% incidence, dispersion was random or uniform, depending on the type of analysis. In the 0–40% incidence range, which was the range considered to be relevant to disease management, the spatial pattern described by Iwao's method (4) was of slightly aggregated small foci of individual infected tillers. Of the sampled organs investigated, units of both the mean of the top three leaves and of the third leaf from the top of the plant were not significantly affected by season or crop location, but the top-three-leaves unit was the only one for which a spatial analysis with the different methods was consistent. The top-three-leaves unit was therefore selected for implementing the management program.

Relationships Among Incidence, Severity, and Yield Loss

Disease assessment methods should be quick and easy to use (7) and standardized so that several personnel are able to obtain similar results. Percentage standard area diagrams have several advantages, especially because disease may be measured as both the incidence (proportion of infected units) and the severity (degree of damage per unit). Although severity is often closely related to yield loss, the measurement of severity is not well suited to monitoring of disease levels by growers in their own fields. We decided, therefore, to analyze incidence/severity and severity/yield loss relationships for the management plan.

We investigated the incidence/severity relationship with the same data used for spatial analysis. At incidences less than 40%, for which incidence and severity are often highly correlated, the mean values on the top-three-leaves sample unit had the highest correlation between incidence and severity, and the relationship was consistent between seasons and sites (Table 3), as tested by the lack of significant differences between the slopes of the regression equations for different seasons. This sample unit and relationship was therefore selected for management implementation.

Economic injury levels are defined as the amount of pest that causes a reduction in crop value greater than the cost of control. Action levels, the pest level at which control is judged to be necessary to avoid significant yield loss, are derived subjectively but can be used as criteria for fungicide use when economic thresholds and economic injury levels are difficult to establish.

We investigated the effect of stripe rust on yield and yield development by using fungicide sprays in large plots (Figs. 4 and 5) to manipulate the epidemics in several locations for three seasons. We were interested in identifying the growth stages at which the crop was most sensitive to disease and in comparing empirical models of the severity/yield loss relationships with published models and with the observed effects on yield components.

Seed treatment, used in most experiments, was shown to control disease for at least 30 days, thus defining the four- to five-leaf stage as the growth stage before which disease control need not be considered. Also, fungicides applied after flowering did not increase yields

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Dr. Gaunt received his B.Sc. degree in agricultural botany from University College of North Wales, Bangor, and his Ph.D. degree on the physiology of host-parasite interactions in wheat loose smut from Southampton University. After 4 years of lecturing on plant pathology and plant physiology at Rhodes University in Grahamstown, South Africa, he took up his present position as senior lecturer in plant pathology at Lincoln University College in Christchurch, New Zealand. For the past 10 years, he has lectured on the broad aspects of pathology to professional-degree students and has done research on epidemiology, yield loss, and seed pathology. His main interest has been the physiological basis of yield loss and the development of mechanistic production models for management and other purposes. He has traveled extensively to Europe and the United States and is active with international groups involved in crop loss and epidemiology.

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Dr. Cole received his B.Sc. degree in entomology and plant pathology and his M.Sc. degree on pest population monitoring in cotton from the University of Arizona in Tucson. He was awarded a postgraduate fellowship at Lincoln University College in Christchurch, New Zealand, which led to a Ph.D. degree in plant pathology. The topic of his thesis is reviewed in this article. His current interests are in the research/extension interface in pest and disease management.

(1). Applications of fungicide between the emergence of the fifth leaf and flowering increased both grain number per ear and grain weight, the dominant effect varying between season/location and time of treatment.

Linear and quadratic regression critical point models were fitted at several growth stages, with no growth stage giving consistently high correlations (Table 4). Also, the models showed little agreement with European and American empirical models, possibly because the epidemic occurred earlier and lasted longer and because plant growth and development were different. Growth stages identified by critical point models were not consistent with our physiological interpretations of the effects of disease based on an understanding of yield physiology (1) and analysis of yield components. Fungicides applied between the beginning of stem extension and ear emergence consistently gave the best yield responses, and these responses could be related to applications at disease severity levels between 0.1 and 0.4% on the top three leaves (1). A conservative action level of 0.2% was chosen for implementing a management plan to allow for possible delays in fungicide application after the action level was reached.

Fig. 4. Spray rig used for applying fungicides from the edge of a treatment plot.

Sequential Sampling Plan

To be accepted commercially, pest management plans must be rapid and reliable. The goal is fast classification of pest populations relative to a predetermined threshold or action level, rather than the precise estimation of population frequencies and distributions required for research. Sequential sampling is such a method, based on a flexible sample size related to the spatial pattern of the pest, predetermined action levels, and a chosen confidence level for making correct decisions (9). Pest populations are classified as being below a lower limit, where control is not required, or above an upper limit, where control is recommended. Intermediate levels require continued sampling until a decision is reached. At small or large populations relative to the action level, decisions are reached very quickly, but a larger number of samples is required if the population is close to the action level. Thus, sequential sampling has the potential to reduce sampling considerably (50–70%) and is well suited to a regular monitoring program.

Many sequential sampling systems require that a frequency model be fitted to the data, but Iwao's system (5) avoids this. We developed such a sampling plan, using two equations for the upper and lower acceptance levels: $T_{\text{upper}} = nx + t[n(a+1)x + (b-1)x^2]^{½}$ and $T_{\text{lower}} = nx - t[n(a+1)x + (b-1)x^2]^{½}$, where T = the threshold value, n = the number of sample units examined, x = the action level, and t = the value of the Student's t test at a chosen level of significance for a two-sided test and an infinite number of degrees of freedom. Values of a and b are the intercept values and slopes, respectively, from the regression of mean crowding and mean density (5).

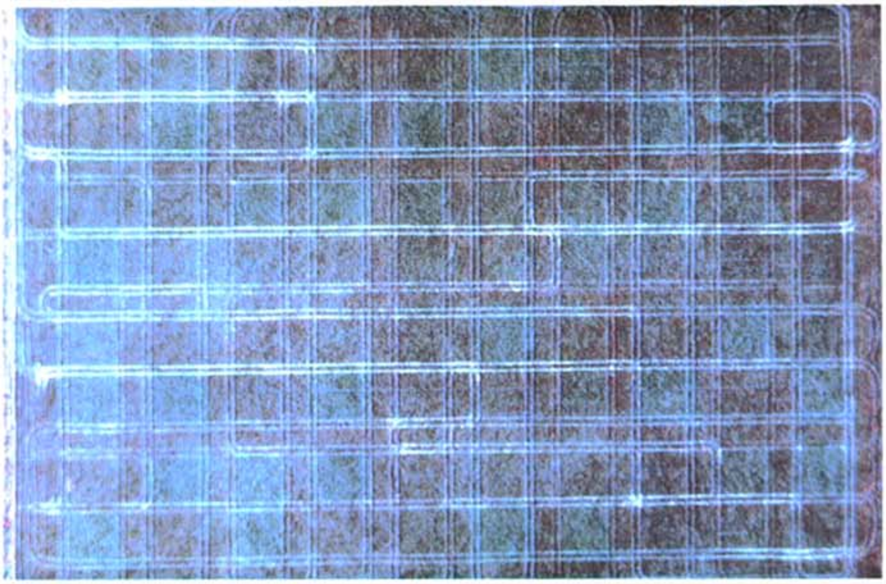

Fig. 5. Aerial view of an experimental site showing treatment plots delimited by tractor wheel lines. The photograph was taken with an aircraft-mounted camera using infrared-sensitive film. Diseased plots appear green and healthy ones appear red.

The sample unit was the top three leaves on 10 consecutive tillers examined at regular intervals on a "W" pattern in the field. The action level was 0.2% severity, estimated by an incidence of 10%. The spatial pattern was described by the parameters derived from the regression of mean crowding on mean density (1). Finally, a 90% confidence level (t = 1.64) was chosen as an appropriate risk of making an incorrect decision. To avoid the problem of a potentially large sample size if no control decision was reached, Iwao's equation (5) was used to calculate the maximum sample number beyond which the pest population could be assumed to be greater than the action level, as shown by: $n_{\max} = t^2[(a+1)x + (b-1)x^2]/d^2$, where d^2 = the confidence interval chosen for the estimation of pest density when the sample mean density equals the action level. Other variables are the same as those described for the equations to calculate the upper and lower acceptance limits.

The decision levels are shown in Table 5. These are combined with the operation rules in a form for growers to use. The operation rules are:

1. Begin sampling at growth stage 15 (five leaves emerged).
2. Start approximately 20 m from each border at the corner of a field, examine the top three fully expanded leaves on 10 consecutive tillers in a row, and record the incidence of stripe rust.
3. Walk in a "W" pattern through the field and examine 10 samples spread evenly along the diagonals. Keep a cumulative total of the number of tillers with stripe rust symptoms.
4. Refer to the decision table. If the cumulative total is less than the lower limit, stop sampling and resample 1 week later. If the total is above the upper limit, stop, spray as soon as possible, and start to resample 3 weeks later. If the total is between the lower and the upper limit, continue sampling until a decision is reached. If no decision is reached after 40 samples, stop, spray as soon as possible, and start to resample 3 weeks later.

The management plan was tested on a limited scale during 1984–1985 by comparing yields and fungicide spray frequency in half fields managed by this plan or by a scheduled plan in common use by good growers. Use of the sequential sampling plan resulted in one less spray application without a significant reduction in yield (1). Control decisions were made in an average of 7 minutes with an average of 11 samples. Decisions were in all cases in agreement with a 40-sample fixed-number plan.

Status at Present

Since the pathogen was introduced, a new race (106 E139) has been found that

Table 4. Significant regressions[a] for critical point models of relationship between stripe rust severity on top three leaves and yield of wheat cultivar Rongotea in three seasons

		Regression models			
		Linear		Quadratic	
Year	Growth stage[b]	Equation	R^{2c}	Equation	R^2
1981	39			$Y = 6.08 - 10.3\,(\mathrm{sev}) + 5.05\,(\mathrm{sev})^2$	0.92
	59	$Y = 3.72 - 0.17\,(\mathrm{sev})$	0.57	$Y = 3.90 - 0.32\,(\mathrm{sev}) + 0.02\,(\mathrm{sev})^2$	0.52
1982	32			$Y = 6.01 + 12.5\,(\mathrm{sev}) - 66.1\,(\mathrm{sev})^2$	0.84
	43	$Y = 6.43 - 1.10\,(\mathrm{sev})$	0.41	$Y = 6.34 + 0.40\,(\mathrm{sev}) - 3.28\,(\mathrm{sev})^2$	0.44
	75	$Y = 6.46 - 0.06\,(\mathrm{sev})$	0.60	$Y = 6.41 - 0.04\,(\mathrm{sev}) + 0.01\,(\mathrm{sev})^2$	0.58
1983	59	$Y = 6.24 - 0.08\,(\mathrm{sev})$	0.62	$Y = 6.57 - 0.16\,(\mathrm{sev}) - 0.01\,(\mathrm{sev})^2$	0.64

[a] Critical point models were tested by regression at growth stages 32–61 (1981), 32–75 (1982), and 23–61 (1983). Only those significant by F test ($P < 0.05$) are included.

[b] Decimal growth stage (16).

[c] Coefficient of variation.

Table 5. Decision table for growers for a sequential sampling plan to assess need for spray control of wheat stripe rust

	Acceptance limits[a]	
Sample	Lower	Upper
10	5	16
11	5	17
12	6	18
13	7	19
14	7	21
15	8	22
16	9	23
17	10	24
18	11	25
19	11	27
20	12	28
21	13	29
22	14	30
23	15	31
24	15	33
25	16	34
26	17	35
27	18	36
28	19	37
29	20	38
30	20	40
31	21	41
32	22	42
33	23	43
34	24	44
35	25	45
36	25	45
37	26	48
38	27	49
39	28	50
40	29	51

[a] Number of tillers with symptoms of stripe rust (see operation rule 4 in text).

is pathogenic on the cultivar Oroua, causing very susceptible reactions. The acreage continues to be dominated by susceptible cultivars. Some recent introductions are resistant, but the stability of this resistance is questionable for at least a few of these new cultivars. Baytan is now used on greater than 95% of seed, and triazole fungicides are used extensively for spray applications. The area sown to wheat has declined, both because of the reaction of growers to the disease and because of market forces. Average wheat yields, however, have increased, an effect that can be attributed in part to heightened awareness of disease problems and of the benefits of good disease management by cereal growers.

Some growers have used the described management plan, and efforts are being made toward wider acceptance. We envisage that in the long term, stripe rust will be controlled by integrating this approach with new resistant cultivars and that several benefits can be expected in terms of an increased acceptance of the principles of integrated pest management in cereals and other crops. An important feature of this management program is the use of disease thresholds derived from a physiological interpretation of yield loss, rather than the use of empirical correlation models.

Acknowledgments

The program was based on interactions between many scientists, extension officers, and growers. The research development of the management plan was carried out at Lincoln University College as part of a Ph.D. study program (MJC). We are grateful to Lincoln University College for providing financial support and facilities, and we wish to thank staff of the Plant Protection Centre, MAF, Lincoln, for Figure 2 and Figure 3 and DSIR, Lincoln, for Figure 5.

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Salute to APS Sustaining Associates

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BASF Wyandotte Corporation, Contact: Earle Butterfield, Ph.D., Fungicide Specialist, 100 Cherry Hill Rd., P.O. Box 181, Parsippany, NJ 07054; 201/263-3904. BASF Wyandotte Corp., a member of the worldwide BASF Group, brings over 100 years of experience and accomplishments to the agricultural field. Backed by a network of highly trained people in research, market development, sales, and management, BASF is helping in the world's vital struggle to produce high yielding, high quality food and fiber crops. As a leader in agricultural chemical research around the world, BASF is firmly dedicated to the continued development of agrichemicals for a growing world.

Buckman Laboratories, 1256 N. McLean Blvd., Memphis, TN 38108; 901/278-0330.

Calgene, Inc., Contact: Robert M. Goodman, Vice-President, Research and Development, 1920 Fifth St., Davis, CA 95616; 916/753-6313. Calgene was founded in 1980 to develop and commercialize new crop varieties and plant products through the use of recombinant DNA and related technologies. Calgene conducts research and development under contract with other corporations, in joint ventures, and on its own behalf. Calgene is developing new crop varieties with commercially useful traits. Product focuses are herbicide tolerance, improved carbohydrate metabolism, and altered vegetable oil biosynthesis. Calgene has successfully introduced an agronomically useful gene (herbicide resistance) into plants and has submitted an application to the USDA for permission to plant recombinant DNA-containing tobacco in California.

Cargill, Inc., Contact: James L. Dodd, Research Station, Box 470, Aurora, IL 60507; 312/892-4331. Cargill, Inc., is actively involved in agriculture from the production of crops to the processing of grain. Research ranges from development of new uses for agriculture products to development of new herbicides and varieties of corn, sorghum, wheat, sunflowers, safflower, and cotton. Use of genetics to control diseases of these crops is a major part of Cargill's international crop breeding efforts, and pathologists participate in each program. Seed from Cargill Seed Research is sold with the brand names of Cargill, P-A-G, Paymaster, and Bounty wheat.

Chevron Chemical Company, Agricultural Chemicals Division, Contact: R. G. Anderson, Director of Research, Ortho Research Center, P.O. Box 4010, Richmond, CA 94804-0010; 415/231-8100. The Agricultural Chemicals Division of Chevron Chemical Co. develops, manufactures, and markets agricultural chemicals including herbicides, fungicides, plant growth regulators, and insecticides for worldwide use.

Chevron Chemical Company, 575 Market St. 3651, San Francisco, CA 94105.

New Sustaining Associate

Alf. Christianson Seed Co., Contact: Dr. Ta-Li Kuan, P.O. Box 98, Mount Vernon, WA 98273; 206/336-9727. Alf. Christianson Seed Co. was founded in 1926. It is committed to development, production, conditioning, and distribution of high quality vegetable seed worldwide. The major crops are beet, cabbage, carrot, collards, kale, mustard, radish, onion, rutabaga, spinach, and turnip. The company has been awarded the U.S. President's "E" Award for its significance to the country's export trade and contributions to the balance of trade in U.S.-World economics. Alf. Christianson supports and cooperates with university and USDA agricultural programs and information exchanges.