RELATION BETWEEN INCIDENCE OF *GAEUMANNOMYCES GRAMINIS* VAR. *TRITICI* AND GRAIN YIELD

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Abstract

A method of using grain yield to estimate the incidence of *G. graminis* var. *tritici* in the field is described. It was found that a map based on yield alone underestimated the actual incidence. However, when incidence and grain yield were coupled by the use of an "incidence–yield" regression established on a few sites, a map showing estimated levels of *G. graminis* var. *tritici* was obtained without destroying the experimental area. Bioassays of stubble and of soil cores were used to establish the actual incidence of *G. graminis* var. *tritici*; the former gave better results.

I. Introduction

For intensive studies of a limited area in the field over a long period of time, it is necessary to develop methods of assessing the incidence of *Gaeumannomyces graminis* var. *tritici* Walker (hereafter referred to as *G. graminis*) with minimum disturbance to the location. Methods based on an above-ground part of the host would be advantageous; suitable parameters could include grain yield, plant height, or straw weight. Grain yield is easily recorded and has the advantage of being the parameter of most interest to the farmer. However, yield alone reveals nothing about the factors, pathogenic or otherwise, that may be present and influencing grain production. For this reason, yield often needs to be correlated with parameters measuring the incidence of *G. graminis*. Suzuki *et al.* (1957) were able to show a close relationship between average yield per plant and infection rating. Nilsson (1969) has shown that a very strong correlation exists between disease rating (based upon degree of root discoloration) and decrease in grain yield. Slope (1967) and Rosser and Chadburn (1968) have established significant regression coefficients for grain yield and percentage of plants infected. The investigation reported below examines the possibility of using yield to estimate the incidence of *G. graminis* with a minimum of disturbance to the field location.

II. Experimental Areas and Methods

(*a*) *At Turretfield*

One experimental area was located on the Turretfield Research Station of the South Australian Department of Agriculture, 10 km north-east of Gawler. Three blocks within the 1969 crop were

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chosen at the end of the growing season for detailed investigation. Each block contained 12 drill rows 3·6 m long and divided into 12 sites 30 cm in length. The blocks were separated by the following distances: A–B, 16 m; B–C, 15 m; C–A, 5 m. The only apparent differences between the blocks were the incidence of take-all and some soil compaction associated with severe take-all and the subsequent lack of ground cover to protect the soil surface from rain. Block A was chosen to represent a location without take-all; nearly all plants were vigorous, being even in height and producing grain-filled heads. Block B was situated in a take-all patch; all plants were small compared to those in block A and many failed to produce heads. Block C contained both vigorous and small plants; a take-all patch extended down most of the western side and there also appeared to be a small patch in the north-east corner (Fig. 1*a*). The heads from the 144 sites in the three blocks were collected, threshed, and the grain weighed. Within each block the plants were removed from 12 sites (one site selected at random per drill row) and the crowns bioassayed for the presence of *G. graminis* (Mac Nish 1973).

(*b*) *At Ceduna*

The other experimental area was on a farmer's property 22 km east of Ceduna. Details of the soil have been described previously (Mac Nish *et al.* 1973). The experimental block within the 1969 crop contained part of a poorly defined take-all patch and a small section in the south-east corner with relatively vigorous plants. The block had 16 drill rows each 4·8 m long and each drill row was divided into 16 sites 30 cm long. From each site the grain yield was recorded. From every second site in the drill row (even numbers in row 1, odd numbers in row 2, and so on), all the plants were removed and the crowns bioassayed for the presence of *G. graminis*. From all the remaining sites a soil core (9·8 cm) was removed from the centre of the 30 cm length of row and bioassayed for the presence of *G. graminis* (Mac Nish *et al.* 1973).

III. Experimental Details and Results

(*a*) *Turretfield Location*

The aim of this experiment was to determine whether the yield results from blocks A and B could be used to predict the incidence of *G. graminis* in block C. Two approaches were employed. Firstly, the variability of yield within blocks A and B was examined to determine the sample size necessary to differentiate between these two blocks; the estimated incidence in block C was then mapped, based on the yields in blocks A and B. Secondly, the regression of the incidence of *G. graminis* and grain yield was established, then used to predict the yield at selected levels of incidence. The maps obtained by the two methods were then compared. Because of the large amount of data involved, yield and incidence results are presented (Table 1) from only the 12 random sites within blocks A, B, and C.

(i) *Incidence Map based on Yield*

To examine the variability in yield, it was assumed that A was a uniformly high-yield, low-incidence block, while B was a uniformly low-yield, high-incidence block. If this assumption was correct it should be possible to divide block C into parts similar to both A and B, and possibly some sections intermediate to both. However, there was considerable variability of yield between sites within both A and B. The range of the distribution within which the yield from 95% of the sites was expected to fall is shown in Table 2. The results for 144 sites (12×12) show that the limits for the 95% ranges for blocks A and B overlap (4·5–20·1 and 0–6·6). This means that the use of sites of this size (i.e. one drill row by 30 cm) to establish limits of the incidence of *G. graminis* for block C is impractical, as the sites within

TABLE 1

NUMBER OF PLANTS, GRAIN YIELD, AND LEVEL OF INFECTION FROM 12 RANDOM SITES IN EXPERIMENTAL BLOCKS AT TURRETFIELD

Row	Site	No. of plants	Total yield (g)	Av. yield (g)	Infected crowns (%)	Row	Site	No. of plants	Total yield (g)	Av. yield (g)	Infected crowns (%)
			Block A						**Block B**		
1	6	23	19	0·83	30	1	4	10	3	0·30	60
2	12	10	14	1·40	20	2	10	14	0	0	100
3	1	13	21	1·62	15	3	7	10	1	0·10	90
4	9	8	10	1·25	38	4	12	8	1	0·13	100
5	10	20	17	0·85	10	5	12	9	4	0·44	100
6	1	11	8	0·73	64	6	7	9	1	0·11	100
7	10	8	15	1·88	13	7	8	7	2	0·29	100
8	7	12	9	0·75	8	8	5	9	0	0	100
9	12	11	9	0·82	36	9	12	12	0	0	100
10	9	19	13	0·68	10	10	7	6	4	0·67	100
11	10	9	11	1·22	33	11	8	8	1	0·13	100
12	4	17	13	0·76	24	12	9	14	1	0·07	93
Mean		13·4	13·3	1·07	25·1	Mean		9·7	1·5	0·19	95·3
			Block C						**Block C**		
1	6	18	7	0·38	78	8	8	11	8	0·73	55
2	8	13	0	0	100	9	11	12	13	1·08	58
3	10	10	4	0·40	100	10	7	9	8	0·89	56
4	8	23	2	0·09	100	11	1	11	0	0	100
5	5	12	16	1·33	92	12	8	15	12	0·89	93
6	10	10	2	0·20	100						
7	1	9	14	1·56	67	Mean		12·8	7·3	0·62	83·3

TABLE 2

RANGE OF THE DISTRIBUTION WITHIN WHICH THE YIELD FROM 95% OF THE SITES IS EXPECTED TO FALL FOR BLOCKS A, B, AND C AT TURRETFIELD

Each block was divided into 144 sites (12 × 12) or into 36 macro-sites (6 × 6; see text). 95% range = $\bar{\chi} \pm$ S.D. × t, where $\bar{\chi}$ = mean grain yield (g) per site or macro-site

Block	$\bar{\chi}$		S.D. × t		95% range (g)	
	12 × 12	6 × 6	12 × 12	6 × 6	12 × 12	6 × 6
A	12·3	49·1	7·8	15·0	4·5–20·1	34·1–64·1
B	2·2	8·7	4·4	8·1	0–6·6	0·6–16·8
C	8·1	32·6	9·4	27·0	0–17·5	5·6–59·6

the so-called uniform blocks A and B were too variable. However, if four sites are combined to make one macro-site (two drill rows wide by 60 cm long) the variability is reduced and the ranges for blocks A and B in which the yield from 95% of the macro-sites is expected to fall do not overlap (Table 2). All macro-sites with a yield of 34 g or more are considered to be similar to block A (based on the lower limit of

the 95% distribution range) and therefore have a low incidence of *G. graminis*. Macro-sites with yields of 17 g or less are considered to be similar to block B (based on the upper limit of the 95% range).

When the above limits were applied to block A, one macro-site was placed in the intermediate-incidence division and the remaining 35 in the low-incidence grouping. One macro-site in block B was classed as intermediate, while the remainder were high-incidence macro-sites. The macro-site grain yields for block C (6×6) are shown in Figure 1(*b*). Superimposed are three levels of estimated incidence of *G. graminis*. The map produced is similar to the visual assessment (Fig. 1*a*) made prior to harvest. However, a large number of macro-sites are classed as low-incidence areas and, as can be seen from Table 1, this is probably not the case. The inference is therefore that mapping the incidence of *G. graminis* by grain yield alone results in underestimation of the actual incidence. The map based on yield alone possibly gives an indication of early levels of *G. graminis* rather than actual incidence at the end of the season.

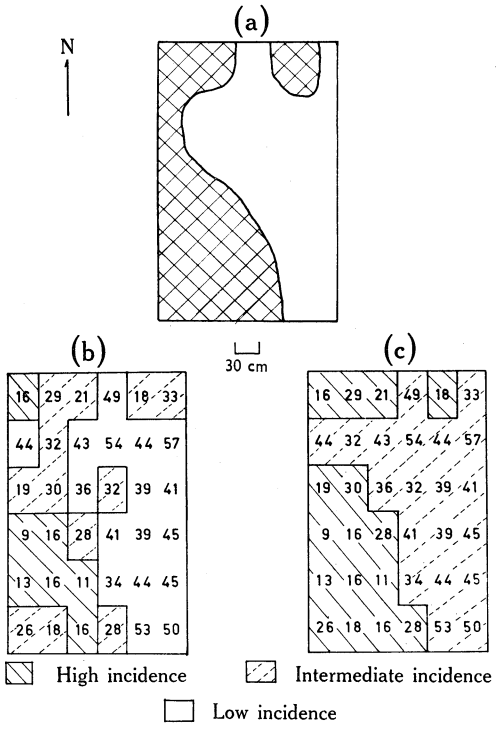

Fig. 1.—Take-all mapping experiments on block C at Turretfield. (*a*) Map based on visual assessment (cross-hatching indicates take-all areas). (*b*) Map based on results of grain yield from adjacent take-all and non-take-all blocks (high-incidence macro-sites, yield $\leqslant 17$ g; intermediate, 18–33 g; low, $\geqslant 34$ g). (*c*) Map based on the regression of infected crowns and grain yield (see text) (high-incidence macro-sites, yield $\leqslant 30$ g; intermediate, 31–60 g).

(ii) *Incidence Map based on "Incidence–Yield" Regression*

In the second approach the correlation of actual incidence of *G. graminis* and grain yield was studied. Correlation coefficients and analyses of variance for regressions comparing percentage of infected crowns with number of plants, total grain yield, and average yield per site were computed for blocks A, B, and C (Table 3). In

no instance was incidence correlated with the number of plants per site and only in block C were incidence and average yield correlated ($P = 0{\cdot}05$). As all blocks were located in the same vicinity, with no obvious difference in soil type and no pathogens of importance other than *G. graminis*, regressions using the combined data from all

TABLE 3

RESULTS OF THE REGRESSION ANALYSIS FOR COMPARISON OF PERCENTAGE OF CROWNS INFECTED WITH THE NUMBER OF PLANTS PER SITE AND GRAIN YIELD PER SITE FOR BLOCKS A, B, AND C (INDIVIDUALLY AND COMBINED) AT TURRETFIELD

Parameters	Block	Variance ratio	Correlation coefficient (r)
Percentage infected crowns			
v. No. of plants	A	0·8	0·2805
	B	0·2	0·1454
	C	1·1	0·3137
	Combined	2·6	0·2665
Percentage infected crowns			
v. total yield	A	3·2	0·4909
	B	0·9	0·2793
	C	4·2	0·5428
	Combined	56·0***	0·7888
Percentage infected crowns			
v. average yield	A	0·5	0·2187
	B	0·1	0·1094
	C	6·1*	0·6169
	Combined	34·2***	0·7081

* $P < 0{\cdot}05$. *** $P < 0{\cdot}001$.

sites were calculated (Table 3). The percentage of infected crowns was significantly ($P = 0{\cdot}001$) correlated with both total and average yield. It is of interest that the correlation coefficient for the percentage of infected crowns is higher with total grain yield than with average yield. Calculation of average yield is a problem because of the difficulty in counting the number of plants per site (i.e. determining which are plants and which are tillers). It is possible that tillering removes gaps caused by variation in numbers of plants and this may be the reason that total yield is better than average yield for making comparisons with disease incidence.

The relationship between infection and total yield is shown in Figure 2. This regression has been called an "incidence–yield" regression and was used to calculate the expected yield for any level of incidence of *G. graminis*. To delimit boundaries for incidence categories, two arbitrary levels were selected. All sites with 67% or more of the crowns infected were called high-incidence sites, while those with 33% or less were called low-incidence. When these points are applied to the regression in Figure 2, it can be calculated that high-incidence macro-sites would have a yield of 30 g or less ($7{\cdot}5 \times 4$ to bring site yield to macro-site equivalent). Similarly, those macro-sites with a yield of 61 g or more would be in the low-incidence category.

Using the above categories all except two macro-sites in block A would be mapped as intermediate incidence. The two exceptions would be low-incidence macro-sites. Although block A was visually disease-free, the bioassay of crowns suggests that about 25% of the plants were infected (Table 1). All of block B would be in the high-incidence category. When the above incidence levels are superimposed on the yield map for block C (Fig. 1*c*), only high- and intermediate-incidence macro-sites are obtained. Examination of the results for block C (Table 1) suggests that, although the yield mean is intermediate to that observed for blocks A and B, the percentage of infected crowns is heavily biased towards that found for block B (i.e. high incidence). This in turn indicates that all of block C should be in either the high or intermediate categories. The map (Fig. 1*c*) using the incidence–yield regression and based on the arbitrary categories for levels of infection portrays this condition better than the map (Fig. 1*b*) based on yield alone.

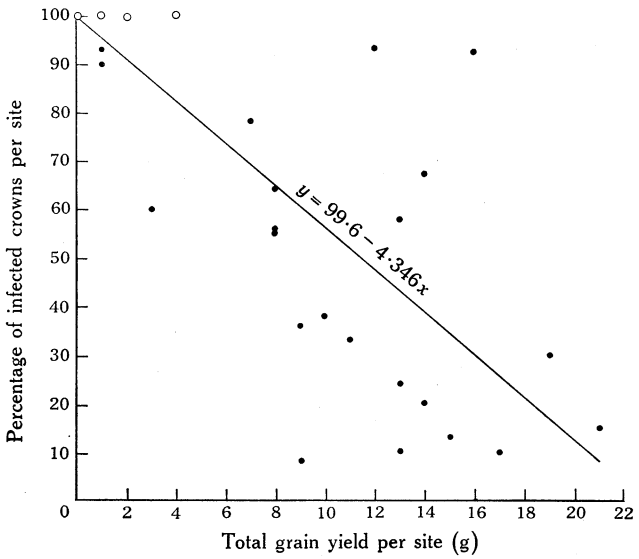

Fig. 2.—Relationship between percentage of infected crowns and total grain yield for 36 sites at Turretfield. ○ Two or more points coincident.

(*b*) *Ceduna Location*

At Turretfield only 36 sites were used to establish the incidence–yield regression. In the experiment conducted at Ceduna regressions were established using 128 samples. Because of the large amount of data involved, only the processed data are presented (Table 4). The percentage of infected crowns per site was not influenced by the number of plants per site, but the variance ratios for the other relationships were highly significant ($P = 0{\cdot}001$). As previously found, the correlation between percentage of infected crowns and total grain yield was superior to that between percentage of infected crowns and average yield.

(i) *Comparison of Methods of determining Incidence of* G. graminis

With the regression equations established, a series of maps was prepared based on (1) the relationship between incidence of *G. graminis* and grain yield, and (2) incidence alone. These maps were then compared.

TABLE 4

RESULTS OF THE REGRESSION ANALYSIS FOR COMPARISON OF THE PERCENTAGE OF INFECTED CROWNS PER SITE WITH NUMBER OF PLANTS AND GRAIN YIELD FROM EVERY SECOND SITE, AND OF THE PERCENTAGE OF INFECTED ROOTS PER CORE WITH YIELD FROM THE ALTERNATE SITES, IN AN EXPERIMENTAL BLOCK AT CEDUNA

y	*x*	Variance ratio	Correlation coefficient (*r*)	Regression equation
		Crown bioassay		
Percentage crowns infected	No. of plants per site	3·7	0·1766	—
As above	Total yield per site (g)	139·7***	0·7377	$y = 100{\cdot}69 - 9{\cdot}95x$
As above	Average yield per site (g)	79·8***	0·6368	$y = 97{\cdot}45 - 41{\cdot}90x$
		Core bioassay		
Percentage roots infected	Total yield per site (g)	53·4***	0·5470	$y = 78{\cdot}61 - 7{\cdot}51x$

*** $P < 0{\cdot}001$.

If the arbitrary points selected previously (i.e. 33% and 67%) are used in that part of the experiment employing the percentage of infected crowns, it can be calculated from the regression curve in Figure 3(*a*) that low-incidence macro-sites

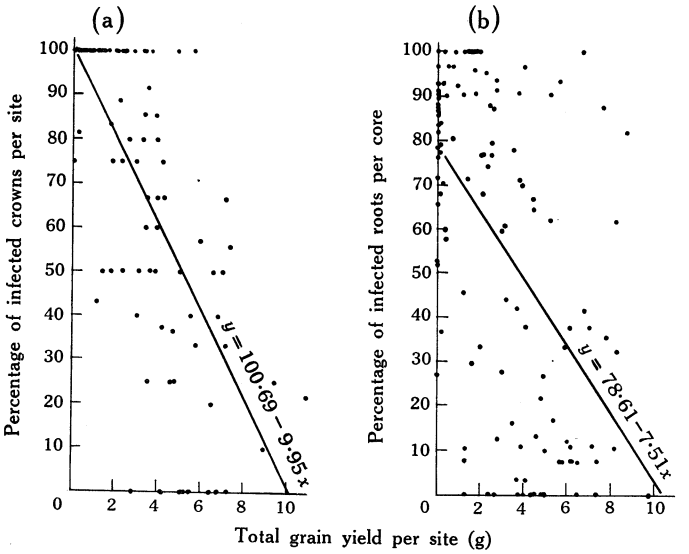

Fig. 3.—Incidence–yield regressions for experimental block at Ceduna: (*a*) relationship between percentage of infected crowns and total grain yield per site, and (*b*) relationship between percentage of infected roots per core and total grain yield per site.

would have a yield of 27 g or more while high-incidence macro-sites would have a yield of 14 g or less. If these categories are superimposed on the yield map shown in Figure 4(*a*), a map (called "incidence–yield" map) predicting the incidence of

G. graminis is obtained. If the actual incidence map based on the percentage of infected crowns per site is drawn (Fig. 4*b*) with the same delimiting points (33% and 67%) it can be seen that the maps are very similar. The map in Figure 4(*a*) has underestimated the parts shown as low incidence in Figure 4(*b*), but otherwise the maps show a good correlation.

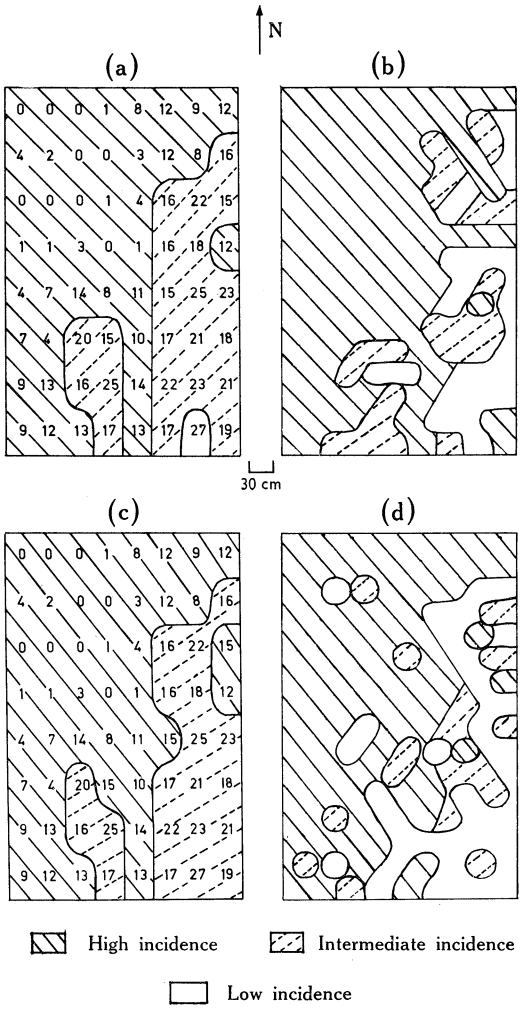

Fig. 4.—Take-all mapping experiments at Ceduna. (*a*) Incidence–yield map, based on the regression of percentage of infected crowns per site and yield superimposed on the grain yield map (high-incidence macro-sites, yield ≤14 g; intermediate, 15–26 g; low, ≥27 g). (*b*) Actual incidence map, based on the percentage of infected crowns on every second site (high incidence, 68–100%; intermediate, 34–67%; low, 0–33%). (*c*) Incidence–yield map, based on the regression of percentage infected roots per core and yield per site superimposed on the grain yield map (high-incidence macro-sites, yield ≤15 g; intermediate, 16–27 g). (*d*) Actual incidence map, based on the percentage of infected roots per core taken from the centre of every second site (high incidence, 51–100%; intermediate, 26–50%; low, 0–25%).

The regression curve for the percentage of infected roots per core and total grain yield per site (Fig. 3*b*) intercepts the *y* axis at 78·6%. If the arbitrary points of delimitation are again selected to represent three equal portions of the *y* axis, the upper limit for low incidence would be 26·2% and the lower limit for high incidence would be 52·4%. As these points were difficult to fit into the computer mapping program used, the limiting points were chosen as 25% or 15 g and 50% or 28 g. When these limits are used to superimpose the estimated incidence of *G. graminis* on the grain yield results (Fig. 4*c*), the resulting incidence–yield map is similar to the map shown in Figure 4(*a*). When the actual incidence map (based on percentage of infected roots) is drawn (Fig. 4*d*), it is similar to its incidence–yield counterpart (Fig. 4*c*). However, the map shown in Figure 4(*d*) is more patchy than that shown in Figure 4(*b*). This indicates that one or both bioassay methods are giving an incorrect estimate of the incidence of *G. graminis*. As exactly half the entire row-length (30 cm in every 60 cm) was sampled to determine the percentage of infected crowns, while slightly less than a sixth of the entire row-length (9·8 cm in every 60 cm) was sampled with the soil cores, it could be expected that the results from the crowns would give a better indication of incidence of *G. graminis* than those from the cores.

In conclusion, it can be seen that the percentage of infected crowns per site and, to a lesser extent, the percentage of infected roots per core show a good correlation with grain yield when intensive sampling of a limited area is undertaken. Such sampling destroys the area and thus there was a need to know the number of samples required to give consistent regression equations.

(ii) *Numbers of Samples needed to determine Incidence–Yield Regression*

A series of regression analyses was performed on the results of the Ceduna experiment. For both bioassay methods (crowns and cores) a random selection of one, two, three, or four samples per row (4·6 m) was compared with the grain yield from the same sites. The regression curves obtained were then compared with the original regression equation based on the maximum number of sites per row (8). The results (Fig. 5) show that at least two sites per row are needed for both types of assay to obtain a regression similar to that obtained from eight sites per row. These observations would indicate that the number of samples taken in the Turretfield experiment (one per 3 m of row) may have been insufficient to establish the correct regression. However, the use of sample sites from take-all and non-take-all blocks at Turretfield would have compensated for the low number of samples per row.

IV. Discussion

The results reported here suggest that mapping the incidence of *G. graminis* by grain yield can be undertaken. However, correlating yield with incidence could be confounded by other pathogens and by variability of the soil and differences in moisture stress. Also, the same level of incidence may give different yields in different years. The first of these problems may be overcome in two ways. Firstly, a close observation of the experimental area is needed to establish that no other major pathogens are influencing yield. Secondly, areas within or adjacent to the trial must be kept and used to establish the incidence–yield regression on each occasion that

the experiment is planted. The problem of variability of soil type within the experimental area is more important. The area selected for experiments should have a uniform soil type. If different soil types are present, it would be preferable to conduct separate experiments on each soil type. If there is considerable variability and the different soil types are too diverse to conduct individual experiments, the incidence–yield approach should not be employed.

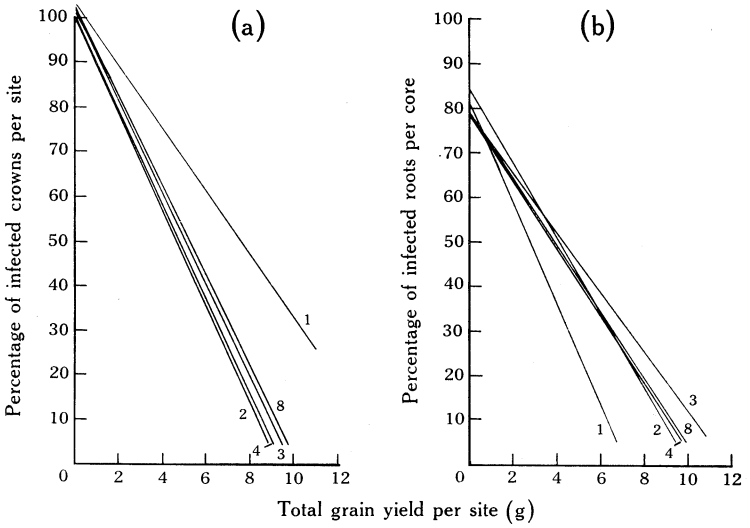

Fig. 5.—Effect of number of samples per row on incidence–yield regression. (*a*) Relationship between percentage of infected crowns per site and total grain yield per site; (*b*) relationship between percentage of infected roots per core and total grain yield per site. The numbers on the regression lines indicate the number of samples taken per row.

Another difficulty that could be encountered when using this technique could be the establishment of the incidence–yield regression when all the area is relatively healthy or uniformly diseased. Also, if the equilibrium situation reported by Fellows and Ficke (1934, 1939) and Buddin and Garrett (1941) is established, there could be difficulty in obtaining a meaningful incidence–yield regression (i.e. incidence may be relatively high with little effect on yield).

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