Special Report

DISTRAIN: A Computer Program for Training People to Estimate Disease Severity on Cereal Leaves

J. R. TOMERLIN, Germplasm Quality and Enhancement Laboratory, Plant Genetics and Germplasm Institute, and T. A. HOWELL, Research Automation Staff, United States Department of Agriculture, Agricultural Research Service, Beltsville, MD 20705

The visual assessment of disease is a fundamental aspect of many phytopathological research projects, including epidemiological studies (3), fungicide studies (10), crop loss assessment (4), and evaluation of parent and progeny plants for disease resistance (1). Progress has been made in developing new methods for assessing plant disease, such as computer-assisted image analysis (8,9) and remote sensing (11). Such instruments may not be available to all researchers, however, nor are they usually designed to distinguish different diseases on a plant or within a field. Consequently, the estimation of disease severity is a basic skill required of plant pathologists, agronomists, plant breeders, crop management specialists, and extension agents.

Problems with standard diagrams

The most common method of estimating disease severity is to compare the diseased plant tissue to standard diagrams on which the silhouettes of disease lesions are arrayed (5,7). Standard diagrams do not display the variegated patterns of many plant diseases. The diagrams include various levels of severity, and the observer attempts to fit the pattern on the actual leaf to a severity level included in the set of diagrams. Although some recent diagrams incorporate distribution and aggregation (2), most standard diagrams offer one "picture" of a given level of severity. The observer must fit a multitude of observed disease patterns having the same severity level to a single representation of that severity level on the standard diagram.

Another problem with standard diagrams is that the observer is not able to evaluate how close the estimated severity is to the actual severity. This shortcoming is particularly important while the skill of severity estimation is being learned. Conceivably, a person could be trained to a fairly high level of consistency. That person's estimates could be consistently incorrect, however, and not comparable to estimates made by others.

A program that mimics diseases

We developed the DISTRAIN program as a means to train people to estimate

Table 1. Comparison of percent disease severity calculated by the DISTRAIN program to that measured by image analysis

Disease	DISTRAIN[a]	Image analysis[b]	Minimum[c]	Maximum[c]	Significance[d]
Leaf rust	40	41	10	73	ns
Net blotch	50	51	4	84	ns
Powdery mildew	34	35	12	68	ns
Scald	43	44	12	75	ns
Septoria blotch	53	53	16	83	ns
Spot blotch	46	46	2	81	ns
Stripe rust	30	31	6	54	ns
Stem rust	...[e]	...	...	...	...

[a] Backtransformed means of 20 arcsin square root transformed disease severities calculated by the DISTRAIN program.
[b] Backtransformed means of 20 arcsin square root transformed disease severities measured by image analysis.
[c] Untransformed values from the DISTRAIN program.
[d] Determined by the TTEST procedure of the Statistical Analysis System.
[e] Stem rust subroutine was added to the program after image analysis was completed.

DISTRAIN—Main Driver

1. Establish arrays and initial values of program variables
2. Determine type of monitor
3. Display credits
4. Display disease menu and wait for user to select a disease
5. For each disease trial
   a) Ask user to indicate desired general severity range
   b) Draw a standard leaf
   c) Calculate number of lesions for this trial
   d) Calculate test value, if appropriate
   e) For each lesion in this trial
      1) Calculate lesion position on the leaf
      2) Call proper disease routine to draw the lesion
   f) Erase portions of lesions beyond the leaf edge
   g) Calculate actual severity
   h) Get user's severity estimate and compare to actual value
   i) Give user the option to:
      1) Do another trial of the same disease
      2) Return to the disease menu and select another disease
      3) Display a summary of results
      4) Exit the program

Fig. 1. Pseudocode outline of the main program showing the general program structure.

Present address of first author: Environmental Protection Agency, Hazard Evaluation Division, Residue Chemistry Branch (TS 769C), 401 M Street SW, Washington, DC 20460.

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disease severity. The program mimics eight common diseases of small grains: leaf rust, powdery mildew, Septoria blotch, scald, spot blotch, net blotch, stripe rust, and stem rust. The estimate entered by the user is compared to the actual "diseased" area displayed on the computer monitor. By using the DISTRAIN program, an inexperienced person could be trained to estimate disease severity and also could develop confidence because the program provides immediate evaluation. The program uses actual percentage of leaf area affected, unlike some diagrams, such as the modified Cobb scale for leaf rust (5).

The DISTRAIN program is written in Microsoft QuickBASIC Version 4.0 (Microsoft Corporation, 16011 NE 36th Way, Box 97017, Redmond, WA 98073-9717), a compiled version of BASIC that results in faster program execution than interpretative BASIC. An assembler routine is used for making a tally of the percent area covered by lesions because a comparable BASIC subroutine was much too slow for use in a training program of this type. The program should run on most IBM compatible personal computers equipped with 128K of RAM memory, a Color Graphics Adapter (CGA), and DOS version 2.0 or higher.

The DISTRAIN program is written for medium resolution (320 × 200 pixel CGA) graphics and uses a four-color palette. Consequently, the appearances of the diseases approximate reality with varying degrees of success. The background is blue, healthy leaf tissue is green, chlorotic tissue and stripe rust uredinia are yellow, and necrotic tissue

Disease 1—Leaf rust

1. Get a random test value from the main program
2. If the test value is larger than an upper threshold, all lesions are susceptible and will be portrayed as four adjacent red pixels drawn longitudinally on the leaf
3. If the test value is smaller than a lower threshold, all lesions are resistant and will be portrayed as single red points surrounded by yellow
4. If the test value is between the upper and lower thresholds, each lesion will be independently determined to be resistant or susceptible and drawn accordingly

Disease 2—Powdery mildew

1. Determine the shape parameter from a random number function
2. Calculate lesion diameter as the product of two randomly selected numbers
3. Draw the lesion and color it yellow

Disease 3—Septoria blotch

1. Calculate lesion shape parameter from a random number function
2. Calculate lesion diameter as the product of two randomly selected numbers
3. If an independent random number exceeds an upper threshold, store lesion diameter, position, and shape parameter in a 'necrotic array'
4. If an independent random number does not exceed an upper threshold, draw a chlorotic (yellow) Septoria lesion
5. After all lesions have been calculated
   a) Draw a necrotic (red) lesion for each lesion stored in the 'necrotic array'

Disease 4—Scald

1. Calculate lesion shape parameter from a random number function
2. Calculate lesion diameter as the product of two randomly selected numbers
3. Draw chlorotic (yellow) scald lesion
4. Store lesion shape, diameter, and position in a 'necrotic array'
5. After all lesions have been drawn
   a) For each lesion, draw a necrotic (red) border for the lesion if an independent random number exceeds an independent upper threshold

Disease 5—Spot blotch

1. Calculate chlorotic lesion diameter as the product of two randomly selected numbers
2. Calculate shape parameter of chlorotic lesion
3. Draw chlorotic (yellow) lesion
4. Calculate position of necrotic lesion and store it in a 'necrotic array'
5. After all lesions have been calculated
   a) Calculate necrotic lesion diameter as the product of two randomly selected numbers
   b) Calculate shape parameter of necrotic lesions
   c) Draw necrotic (red) lesions

Disease 6—Net blotch

1. Calculate lesion shape parameter
2. Calculate lesion diameter
3. Draw chlorotic (yellow) lesion
4. Calculate starting point for 'net' striations
5. Calculate length of 'net' striations
6. Draw longitudinal 'net' striations
7. Draw transverse 'net' striations

Disease 7—Stripe rust

1. Calculate lesion length
2. Draw lesion

Disease 8—Stem rust

1. Calculate size factor
2. Calculate lesion size
3. Draw lesion (yellow)
4. Calculate uredinium size as product of lesion size and size factor
5. Store uredinium size and location in uredinium array
6. After all lesions have been drawn
   a) Draw the uredinium (red) for each lesion

NOTE: Lesions of powdery mildew, Septoria blotch, scald, spot blotch, net blotch, and stem rust are designed around the basic shape of an ellipse. The lesion shapes for these diseases are modified by a shape parameter.

Fig. 2. Pseudocode outline of the eight disease subroutines called by the main program.

and leaf and stem rust uredinia are red. Even though the replica diseased leaves only approximate the actual appearances of the diseases, the person using the program does gain experience assessing diseased leaves with a variegated appearance.

The program displays a "generic" cereal leaf on which lesions of the selected disease are placed randomly, a procedure that allows the student to estimate the severity of a wide array of disease patterns. Students can build up a store of experience that has been graded, allowing them to make adjustments in subsequent trials, which are also graded, thereby learning from their mistakes.

During test runs of the program, several individuals were surprised at the disparity between their estimates and the actual percentages, particularly for leaf

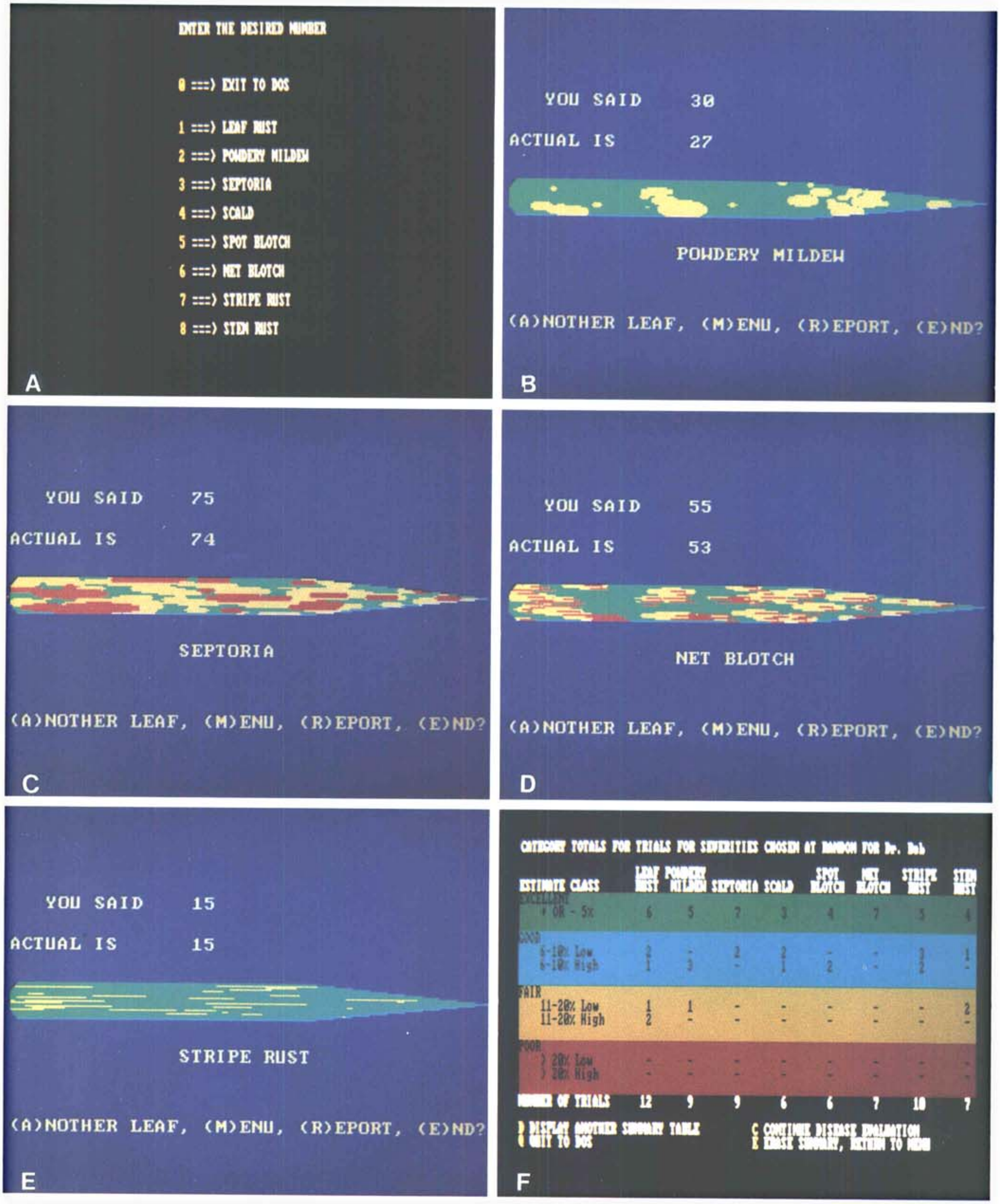

Fig. 3. Typical DISTRAIN screen displays: **(A)** Disease menu, **(B)** powdery mildew, **(C)** Septoria blotch, **(D)** net blotch, **(E)** stripe rust, **(F)** summary report. In the summary report, the user may easily determine how close the estimates are to the actual severities by noting in which bands the estimates are clustered.

rust and stripe rust. Consequently, we took pictures of 20 screens of each disease, except stem rust, with a Polaroid Freeze Frame Video Recorder (Polaroid Corporation, 784 Memorial Drive, Cambridge, MA 02139). The resulting transparencies were examined with an Amersham Research Analysis System Model 1000 image analysis system (Amersham Corporation, 2636 South Clearwood Drive, Arlington Heights, IL 60005). The arcsin square root transformation of the percent area covered by lesions measured by image analysis was compared to that calculated by the DISTRAIN program using the TTEST procedure of the Statistical Analysis System, PC Version (SAS Institute, Inc., Box 8000, Cary, NC 27511-8000). The backtransformed means are shown in Table 1.

How the program works

The pseudocode (English sentence fragment description of program flow) of the main program is shown in Figure 1. The main program functions as a driver that calls the routines which draw the various disease replicas and other functions. A helpful feature of the main program is the option to practice low, medium, high, or random disease severities. The eight disease subroutines are outlined in Figure 2.

The program is started by entering the command "DISTRAIN" at the system prompt. After the program is loaded, the "welcome" screen appears. The user may choose to read the instructions or proceed directly to the disease menu (Fig. 3A).

Once a disease is selected from the menu, the user is instructed to indicate a general severity level. We included this option in case a person wants to practice a particular severity range. For most applications, the random level should be chosen. The next operation is the drawing of the leaf, which appears in the same place on the monitor trial after trial. Once the leaf is drawn, the lesions are placed on the leaf. Some of the lesions may extend beyond the leaf boundary, but a cleanup routine erases the overhanging portions of the lesions before the severity estimate is made.

We assumed that leaf rust lesions would be uniform in size. Consequently, the leaf rust subroutine does not calculate lesion size. In the other disease subroutines, lesion size is calculated randomly, within acceptable ranges, for each disease.

Lesions of powdery mildew, Septoria blotch, scald, spot blotch, and stem rust and the chlorotic area of net blotch are elliptical. Shape parameters for the ellipses are randomly determined; the upper and lower boundaries of the shape parameters were determined empirically. Leaf rust lesions are portrayed as uredinia only or as restricted uredinia with chlorosis, each approximately 30% of the time; the remaining 40% will appear as a mixed infection, with the proportions of uredinia and chlorotic lesions determined randomly.

After the computer determines the percent severity, the user is prompted to enter an estimate of the disease severity, after which the computer displays the estimate and the actual percent severity. Figures 3B and E are typical disease displays.

One of the strong points of the DISTRAIN program is the immediate evaluation of the estimate, allowing the student to make whatever adjustments are necessary to correctly assess disease severity. The program also permits the user to view a report that provides a summary of the difference between the user's disease estimates and the actual leaf area affected (Fig. 3F). Ideally, most of the estimates should fall in the green and blue bands. If most of the estimates fall in the yellow and red bands, the student needs more practice. If desired, a permanent copy of the report may be printed.

Table 1 shows that for each disease, the transformed average disease severity calculated by the DISTRAIN program did not significantly differ from that measured by image analysis. A scatter diagram of untransformed percent severity calculated by the DISTRAIN program and that measured by image analysis (Fig. 4) shows almost a one-to-one relationship, which we interpret as meaning that people using the program can be confident that the program calculates area estimates accurately.

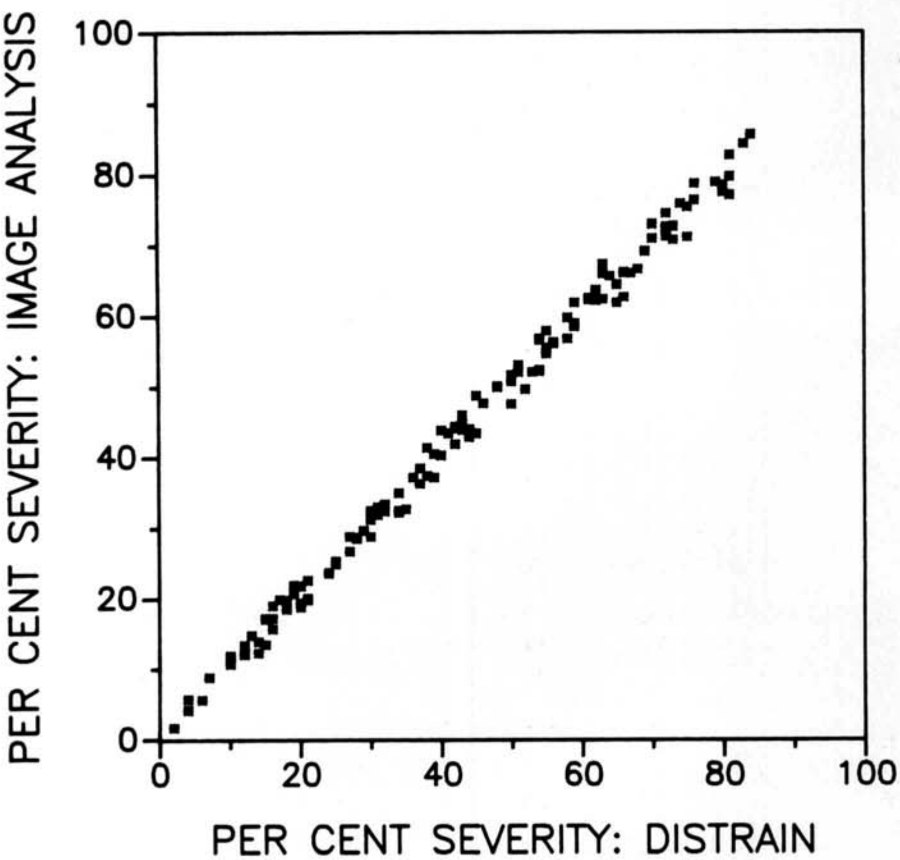

Fig. 4. Scatter plot of percent severity calculated by the DISTRAIN program and measured by image analysis.

Advantages of DISTRAIN

Visual assessment of disease is the only option available to many research programs. Although new methods are being developed and refined (8,9,11), expense, lack of trained personnel, or difficulties in using the equipment in the field disallow their use. Visual assessment is not without problems, however. Lindow (8) theorized that visual estimates of disease severity deviate the most from actual disease at 50% disease. Sherwood et al (13) showed that visual ratings tended to be too high at low disease severities and that even experienced workers were both inaccurate and imprecise. We concur with Gaunt's contention (6) that the research objectives dictate the measurement method. Sometimes the method chosen will be visual assessment of severity. Consequently, the visual estimates should be as accurate and precise as possible. A previous program, AREAGRAM, was developed to train people to estimate disease severities (12). Although AREAGRAM did grade the user's performance, it essentially generated standard area diagrams. The DISTRAIN program exposes the student to random, variegated disease patterns and provides immediate "grading" of the student's performance.

The DISTRAIN program should be of use to anyone engaged in estimating disease severity on cereal leaves. Observers trained by the DISTRAIN program should be able to accurately assess disease severity, which would provide more accurate data for crop loss assessment and to people who have to decide whether or not to apply fungicides. The program could be used to train new workers or to help experienced observers review before beginning field operations. A major advantage of the program over standard area diagrams is that the program can tell the user how close the estimated severity is to the actual severity. If problems are identified, a person can practice until an acceptable level of skill is attained. People within the same laboratory could be confident that the plants are evaluated in the same way by different workers. Extension agents could train growers to scout their own fields and have confidence in their evaluations.

The DISTRAIN program may be obtained by sending a formatted 360K floppy diskette to either author (note address change of the first author). The diskette will be returned with the DISTRAIN executable file, an information file, and listings of the BASIC program and the assembler pixel counting subroutine. The BASIC source code is being distributed in case other workers wish to use DISTRAIN as a guide for writing similar programs for other host/pathogen systems. The program is in the public domain and may be freely copied, so groups or institutions desiring multiple copies of the program should make their own copies upon receipt of the DISTRAIN distribution diskette.

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