METHODS FOR ESTIMATING YIELD LOSS IN TROPICAL RICE DISEASES

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ABSTRACT

The estimation of yield loss caused by diseases requires techniques for a) quantification of the pathogen or disease, b) generation of epidemics of different durations and intensities, c) experiments to provide data for characterizing the disease-loss relationship, d) modeling and e) field surveys. Techniques for (a)-(c) are relatively well-developed for tropical rice, in comparison to techniques for (d) and (e). Disease assessment methods commonly use numerical scales such as 1 (healthy) — 9 (dead) or percentage points. Yield loss experiments have been conducted in greenhouses and the field, using single hills and plots. Regression models have been developed for only a few tropical rice diseases. At IRRI, methods are being investigated to determine yield losses caused by blast, rice tungro virus, bacterial blight and sheath blight. Methodology is also being tested for conducting surveys of multiple pest infestations in farmers' fields. The paper will also describe the methodology used in selected national programs for yield loss assessment.

Introduction

Much of the increase in rice production in tropical Asia resulting from the introduction of the high-yielding varieties (HYVs) since the 1960s may be attributed to improved resistance to diseases and insects. However, in recent years, the resistance to specific diseases has broken down time and again throughout the region, resulting in significant crop losses from diseases such as rice tungro virus (RTV), blast, brown spot and bacterial blight. Historically, epidemics of rice diseases have caused acute food shortages in several countries, the most well-known of which is the "Great Bengal Famine" of 1942/43 attributed to brown spot (Padmanabhan, 1973). Losses caused by diseases which have commonly been considered minor are now causing concern in some countries, for example, false smut in India, which in 1987 caused yield losses and quality up to 10% in some areas.

One question which pathologists at the International Rice Research Institute (IRRI) are particularly concerned with is whether the magnitude of yield losses in farmers' fields has increased because of changing cultural practices such as direct seeding or increased fertilizer use. We are increasingly realizing that information on rice yield and rice losses, as they occur in farmers' fields, is needed to enable the evaluation of changing rice technologies, and to facilitate the understanding of strategic issues in plant protection. For example, we are not aware of any data base that will allow us to make definitive statements on whether losses have increased, decreased or stabilized over the long term. Two recent workshops in Asia — the Pesticide Management and IPM Workshop in Pattaya, Thailand, February 1987, and the Crop Loss Assessment Workshop at IRRI, October 1987 have emphasized the urgent need for crop loss data collected using reliable and acceptable methodology. The extent of crop losses in tropical rice, and models for estimating yield loss due to specific diseases, were recently reviewed by Teng *et al.* (1988). In this paper, we will discuss general approaches for collecting such data, as well as specific methods on the different components of a crop loss program for rice.

Crop loss data may be obtained using different methods, each dependent on the resolution of the

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data required for decision-making (Teng, 1988). There is currently no single method for data collection that has been generally accepted. For convenience, data collection methods are considered to be "indirect" and "direct".

The indirect approach for loss assessment

Developing countries are often reluctant to spend their scarce resources on any activity NOT directly involved in solving a pest control problem. The derivation of crop loss estimates using the following "indirect" methods (Zadoks and Schein, 1979; Van der Graaff, 1981) may be more feasible than the "direct" methods described later, as they invariably make use of existent programs and data.

1 Expert testimony

Knowledgeable scientists are asked to make a "statement of authority" on the extent of loss based on their experience with the crop and diseases in an area. This is perhaps the origin of many of the loss estimates that have found their way into the literature.

2 Enquiries

Estimates are solicited from a broad range of people concerned with the production of a crop in an area, and a consensus is developed on the extent of loss. This approach resembles the "delphi" procedure used in research management.

3 Literature reviews

Published work not specifically designed for loss assessments is evaluated for its value in giving estimates. Examples are multi-location fungicide and cultivar evaluation trials.

4 Field experiments for other purposes

1) Fungicide trials

These trials have as their main objective the assessment of the efficacy and the rate and timing of use of fungicides. Occasionally, however, they can also give information on the relation between yield reduction and disease intensity. The best crop loss data are derived where "complete" protection is included as one of the treatments; one plot is kept disease-free through over-use of pesticides. Location, variety and disease potential should be representative for the area in which the crop is grown. Furthermore, consideration needs to be given to meteorological conditions. To improve the reliability of data from fungicide trials, additional information should be obtained such as: identification of the disease against which the treatment is applied; experimental lay-out; quantitative data on assessment of disease intensity (including growth stage at which records are taken) and, obviously, yield data and statistical analysis. Possible sources of data from pesticide trials other than those published in journals are chemical companies, research stations, and ministries of agriculture as part of their pesticide registration procedures. Obtaining these data will, however, be difficult since they are often confidential.

2) Variety testing trials

These trials will often show important differences with regard to the injury and losses caused by parasites. They might therefore be used for establishing relationships between damage and yield. If a locally grown, popular cultivar is included in these tests, the damage/yield relation derived from the other cultivars may permit the calculation of the yield loss suffered by local growers. To be able to determine the effect of the parasite on the yield, it is necessary that under disease-free conditions the majority of the varieties should yield approximately the same. As in pesticide trials, cultivation practices should not differ from those used by local farmers. Plot locations should be representative for the area, and qualifiers are needed on meteorological conditions. Data recorded from variety trials should also indicate field layout; disease intensity score, and growth stage(s) at which observations were made. Yield records and statistical analysis of yield data should also be available. Sources of data are exclusively research stations.

5 Remote sensing

Satellite imagery or aerial photography is used to estimate crop area, crop yield and crop losses. This technique has worked well for diseases that result in total plant loss, as in some nematode-caused diseases. Few remote sensing data are available for tropical rice environments, and even if they are, no studies have been reported on the spectral patterns of rice diseases that are essential for interpreting the data.

The direct approach for loss assessment

The direct approach uses data that area specifically generated or collected for loss assessment (James and Teng, 1979). The general strategy for using this approach requires the following:

1 Quantification of pathogen/diseases,
2 Generation of epidemics of different durations and intensities,
3 Experiments to provide data for characterizing the disease-loss relationship,
4 Modeling of the disease-loss relationship, and
5 Field surveys.

Each of these will be discussed in the following sections, with emphasis on the current situation and future needs. The reader is referred to Teng (1987) for a comprehensive treatment of crop loss assessment methodology in relation to pest management.

1 Quantification of pathogen and disease

Disease measurement methods are commonly based on the identifiable symptoms caused by fungi, bacteria and viruses, or with nematodes, their numbers per soil or plant unit. In the context of loss assessment, quantification is essential for providing the pathogen/disease "descriptor" used in estimating the relationship between the pathogen/disease and yield or loss.

Disease incidence is the proportion of plants infected in a population, commonly expressed as a percentage, and used with diseases like RTV and panicle blast. Disease severity is the proportion of plant tissue infected and commonly used for pathogens with foliar symptoms, e.g. leaf blast, brown spot. The FAO has used disease intensity to mean either disease incidence or disease severity. Disease assessment is the process of determining disease intensity in a population of plants using an accepted method. Methods in common use by plant pathologists for field disease assessment are disease keys, standards area diagrams, remote sensing, and population counts (James and Teng, 1979). Disease keys and standard area diagrams rely on the determination of severity in comparison with a predefined key or series of diagrams depicting different degrees of severity. A set of disease keys in common use in tropical Asia is the Standard Evaluation System (SES) developed by the International Rice Testing Program (IRTP), in which nine grades of disease are commonly defined. The severity assessed for a plant part like a leaf includes the infected area as well as any accompanying chlorosis or necrosis, and diagrams are available for major rice diseases (Teng, 1975).

A problem in loss assessment is the determination of a representative mean value of the pathogen or disease in a cropping unit using the designated method of assessment. Sampling for diseased population is a relatively under-researched area in comparison with insect sampling, and it was only recently that this has been recognized. The distribution of a pathogen or disease in any spatial unit may be mathematically described as a frequency distribution with estimated parameters, e.g., normal or negative binomial. Preliminary indications of the type of distributions are obtained by examining the mean: variance ratio of the sample mean of disease intensity (Teng, 1983). Knowledge of the type of distribution in a field enables to design a sampling protocol in order to obtain a representative mean in an economical manner. A rule of thumb is to collect disease samples from the two diagonals of a field, since this would account for most of the common distributions known for rice diseases.

Some recent uses of microprocessor technology for disease measurement suggest that we may see more reliable methods in field use in the future. Pederson (1985) has designed a portable, low-cost data acquisition system for measuring canopy reflectances, which may be used for determining the mean effect of a pest on a crop in terms of reduced crop vigor. At IRRI, we have tested this on RTV and blasted plots and have shown that it is possible to distinguish healthy from severely diseased plots using their spectral reflectances. A laboratory-based video image analysis unit was used by Lindow and Webb (1983) to measure the area of infected leaf tissue and proportion of infection. These workers have also begun testing the taping of images of diseased leaves in the field with portable video-cameras and analyzing the images in the laboratory. Image analysis is routinely used for measuring the root area of plants, and it is conceivable that there will be developments allowing its use for measuring nematode number in a sample. Disease severity may also be estimated indirectly, for example from disease incidence, as shown by Surin *et al.* (1988) for leaf blast:

$$\%S = 0.272 + 0.193X - 0.012X^2$$

where S = average percent severity of top four leaves, and X = percent incidence of leaf no. 4 from the top. With sheath blight, severity has been determined by Ahn and Mew (1986) as relative lesion height (= highest height reached by a lesion divided by plant height).

2 Generation of epidemics of different durations and intensities

A basic need in yield loss studies is to generate plots or fields with different amounts of disease, using methods such as fungicide applications at different times, varieties with different resistances, different cultural practices, and different environments. The use of fungicides to modify disease epidemics is probably the most common method. Paired treatment experiments, such as one unsprayed plot and one heavily sprayed plot, should be discounted in favor of multiple treatment plots in which fungicide sprays are selectively applied to modify epidemics. For example, with a 14 treatment (T) experiment, sprays (*) may be applied at different times as follows, with T14 being the unsprayed check:

T1	*	*	*	*	*	*	*	T8							*
T2	*	*	*	*	*	*		T9						*	*
T3	*	*	*	*	*			T10					*	*	*
T4	*	*	*	*				T11				*	*	*	*
T5	*	*	*					T12			*	*	*	*	*
T6	*	*						T13		*	*	*	*	*	*
T7	*							T14	-	-	-	-	-	-	-

The fungicide applications are used to arrest epidemics, to slow them down or to delay the initiation of an epidemic. In using fungicides, it is necessary to test that there are no significant phytotoxic or phytotonic effects on crop growth.

Differential host genotypes to specific diseases, but with approximately similar potential disease-free yields, are a good technique when it is difficult to manipulate epidemics. When this is used in combination with varied planting dates, there is much potential for creating epidemics of different durations and severities. At IRRI, we have varied the environment in blast-yield loss studies by covering some of the plots with plastic at night, as well as inoculating at several times and spraying with a fungicide to reduce infection rate.

3 Experiments to provide data for characterizing the disease-loss relationship

This represents the experimental phase of a disease-loss program, in which field data are collected either from fields with natural epidemics or from experimental treatment plots with different disease intensities.

1) The single tiller/plant method

Fields in any cropping area can commonly be found in one season with varying disease, leading Richardson *et al.* (1975) to use a single tiller method for collecting data to model the disease-loss relationship. In this method, hundreds of tillers (shoots) are tagged, with care being made to select tillers reflecting a wide range of severities, including zero and maximum disease. Fields are visited using a predefined survey procedure, and in each field, disease intensity is assessed and tillers harvested. Each tiller is then a single datum point for regression analysis. The method is a derivation of the paired-plant method, in which pairs of healthy and diseased plants are tagged and observations made on them through the growing season. The advantages of the single tiller or paired plant method are that natural epidemics are used and there is economy of labor, space and time. However, the method has mathematical limitations, and models developed have only been able to explain a small proportion of the variation in yield due to disease. Inter-plant differences in yield are a major source of variation in single tiller/plant studies. Hau *et al.* (1980) improved the method by using measurements of plant parts not affected by disease, but related to potential yield, to correct for differences in observed yield, and were able to reduce some of the variation. We have used single tillers and hills to study bacterial blight and RTV yield losses at IRRI.

2) The synoptic method

In an attempt to determine the effect on what yield from multiple factors, Stynes (1980) developed a "synoptic" procedure in which parts of farmers' fields were intensively sampled throughout the season. Variables measured include disease, insects, nematodes, soil and water properties. Models were developed which explained a significant proportion of the yield variation caused by several factors. A simpler procedure has also been used in developing countries to determine production constraints on farmers' fields at IRRI (de Datta *et al.*, 1981) and in Colombia (Pinstrup-Andersen, 1976). The synoptic method allows crop-loss profiles to be developed, showing the contribution of each constraint in reducing attainable yield to actual yield. In the U.S.A., Wiese (1980) has modified the procedure for field peas but found that the models developed were not stable over seasons. A limitation common to both the single tiller and synoptic methods is that the range of disease severities for each disease may not be wide enough in any season, leading to an underestimation of its importance as a yield constraint.

3) Field plot techniques

Plots arranged using an experimental design such as a randomized complete block are common in crop-loss work. The plots are either paired-treatment or multiple-treatment, where treatments are desired levels of disease or pathogen population. In crop loss assessment, the aim of treatment is to ensure that epidemics with different characteristics are generated using methods that may not necessarily be economical. In the paired-plot approach, healthy (protected) and diseased (unprotected or inoculated plots are situated near each other to constitute a replicate and the pairs repeated over many locations. With multiple-treatment experiments, treatment extremes range from healthy (no disease) to maximum disease, with intervening levels of disease as the other treatments.

An important consideration in plot techniques is the plot size. Although nematologists have generally used microplots, pathologists working with airborne pathogens have had to use larger plots because of the problem of interplot interference. In practice, there is a trade off between reducing inherent yield variation by increased plot size and increasing the variation due to soil factors when plot size is increased. Examples of plot sizes used in rice disease-loss experiments are 10 rows × 6 m (see Teng, 1987), and 25m × 25 m (Torres and Teng, 1988). In general, small plot size, as opposed to large plot size, results in higher between-plot variation and requires a larger number of replicates for the same difference between two treatments to be detected.

Recently, there has been recognition of the inability of standard, experimental designs with replication to provide data that can explain the full range of interaction between crop yield, disease intensity and crop development stage. The relationship between yield loss and disease at different growth stages was conceptualized as a three-dimension response surface, where at each growth stage, disease-loss may be represented by curves (Teng and Gaunt, 1980). To derive a holistic model of the three-dimension surface would require data from a wide range of epidemics, more than can be obtained with replicated experiments. Furthermore, statistical techniques like least-squares regression assume that there is no or minimum variation in the independent variable (disease). With standard experimental designs, this assumption is violated when averaging across replicates while with response surface designs, treatment values may be obtained without variance. We have obtained regression models of leaf blast and panicle blast using this method (Torres and Teng, 1988).

4 Modeling of the disease-loss relationship

A mathematical model is a concise way of representing any system. In yield-loss experiments, the usefulness of the data generated would be limited if the data were not reduced into a simple form. Because of the many forms of the disease-loss relationship, there is no universal mathematical model to fit all these forms. The forms of the relationships range from linear to sigmoid, and Teng (1985) has postulated that there are nine possible shapes of the disease-loss curve. Further, the mathematical description of the relationship depends on the disease descriptor (independent variable) used, such as disease severity at one growth stage or area-under-the disease-progress-curve. With nematodes, the log of nematode density is commonly used as the independent variable. The majority of mathematical models describing the disease-loss relationship has been derived using least squares regression techniques, although recently, simulation modeling has been attempted. With regression models, some workers have suggested that several statistical criteria be used to evaluate each model: F, r, s and t. Furthermore, assumptions in the data collected for modeling need to be recognized and tested. For example, regression assumes that the variables show a normal distribution, yet this assumption is often violated in samples of disease data.

The empirical disease-loss models reported in the literature may be grouped into single-point models, multiple-point models, integral models, response-surface models, non-linear models and synoptic models.

1) Single-point models.

Single-point models relate loss to disease intensity at a specific time in the life of a crop, either a critical growth stage or a predetermined number of days into the growing season. With sheath rot caused by *Sarocladium oryzae*, Surin *et al.* (1988) derived the following equation:

$$\%\text{Loss} = 4.287X - 0.146,$$

where X = sheath rot intensity using the SES scale (0–9) at milky stage. The model explained 62.3% of yield variability and was derived from plot data on transplanted rice cultivar RD23.

James and Teng (1979) have cautioned that fitting a single-point model to a data set does not imply that no other growth stages respond to disease but rather that a particular stage only shows good statistical correlation. Furthermore, it is often necessary to incorporate some physiological knowledge into regression models, to ensure that the models are biologically meaningful. Single-point models are the most common type of disease-loss model in the literature, mainly because they require relatively fewer data to develop. However, their application appears restricted to short-duration, late epidemics with stable infection rates. This type of model assumes that disease dynamics before and after the single point in fields resembles that encountered in the original experiments.

2) Multiple-point models

The multiple-point models relate yield loss to several disease assessments during a crop's life. The disease descriptors used in models have been either disease increments during a defined period or disease intensities at identified growth stages. We are not aware of any multiple point models for rice disease-loss estimation. An example from the literature is the model for estimating wheat-yield loss due to leaf rust (Burleigh *et al.*, 1972) from three growth stages, (percent rust/tiller at boot stage), X2 (percent rust/tiller at boot stage), X5 (percent rust on flag leaf at early drought stage), using the model:

$$\% \text{ Loss} = 5.3788 + 5.5260X2 - 0.3308X5 + 0.5019X7.$$

The workers who developed this model found that even though they could determine several single-point models from the same data the multiple-point model explained the most variation in yield loss due to rust. Multiple-point models are particularly suited for epidemics that are long in duration, have unstable infection rates, and affect more than one yield component.

3) Integral models

Integral models relate loss to a disease descriptor derived from summing disease intensities over a specified period of crop growth. The idea may be attributed to VanderPlank (1963), who proposed the area-under-disease-progress-curve (AUDPC) as a method for analysis of wheat stem rust data. As with multiple point models, we are not aware of any AUDPC model for a rice disease and will therefore use an example from the literature, the model for estimating loss in cowpea due to Cercospora leafspot (Schneider *et al.*, 1976):

$$\% \text{ Loss} = 0.43 \text{ AUDPC} + 14.95$$

In general, AUDPC models cannot distinguish between late or early epidemics since two progress curves with very different onset times and infection areas could give the same area under the curve. AUDPC models have been successfully applied for short-duration, late epidemics. Some workers have improved the predictive ability of AUDPC models by assigning weighting factors to the disease assessments made at different growth stages which are used to calculate the AUDPC.

4) Other models

The relationship among disease, crop growth stage and loss was conceptualized as a three-dimension response surface by Teng and Gaunt (1980) and may be generalized as % Loss = f (disease crop stage), thereby enabling loss estimation if the disease intensity and growth stage are known. This response surface models may also be considered an integrated series of single-point models, and several workers have developed models fitting the concept. Response surface models require substantially more data to develop than the other models discussed previously and have led to research on alternative ways of experimentation to collect data, as discussed in a previous section. At IRRI, we used a response surface model to estimate percent loss (L) due to both leaf blast (B) and panicle blast (P), as follows:

$$L = 0.2101 + 1.0124L + 05102P \text{ (Torres and Teng, 1988)}$$

The majority of disease-loss models have assumed a linear relationship, while it is generally recognized that biological relationships may be non-linear. Madden *et al.*(1981) have modified the

Weibull Distribution Function, with very flexible curve-fitting capabilities, for use on disease-loss relationships, and have demonstrated that good fits to data may be obtained.

More than one model can commonly be found to fit a set of experimental data on any disease-loss system. Although it is generally advisable to collect more data than is necessary for modeling because of the lack of prior knowledge on the form of the model, with some diseases and crops, enough is known of yield physiology to enable postulation of potential relationships. This approach can do much to guide the design of experiments and pinpoint growth stages where it may be useful to have more treatments. Disease-loss modeling must always consider the epidemiological characteristics of the particular disease, such as its duration, infection rates, onset times, if the model is to have practical value (Teng and Johnson, 1987). The intended use of a model is another consideration in determining the form of the model, whether it be single point or multiple point. In surveys, where fields may be visited only once, several different sing-point models would be needed. To forecast potential yield loss may require a multiple-point or integral model that can account for fluctuating rates of disease progress in response to factors like fungicide application.

All empirical models are limited in application by having limited extrapolation value beyond the environment in which they have been developed. Thus, when the potential yield is different or when a cultural practice is changed, such models may become irrelevant. To account for variable environment and biology, crop growth models have been used to predict the potential yield given the environmental data from a particular site. Disease effects are then coupled to the crop model to predict actual yield, and the difference between potential and actual is the loss. At IRRI we have used the IBSNAT/CERES RICE model for coupling blast and leaffolder effects, and have shown that it is feasible to explain the dynamics of the pest and its effect on yield (Teng *et al.*, 1988).

5 Field surveys

Many national programs in South and South-East Asia regularly conduct field surveys for pest surveillance. However, surveys for the sole purpose of collecting crop loss data are uncommon, often *ad hoc* with irregular reports of losses published in sources such as the International Rice Research Newsletter (IRRN). Objective and meaningful estimates of losses can only be obtained if a survey is planned so that the rice environment is sampled to obtain the most interpretative information. Disease survey protocols are well documented (James and Teng, 1979; Teng, 1987; Teng, 1988), and in general, the following is a checklist of considerations for designing a survey:

Cropping environments
Cropping practices
A priori disease zones
Proportional/non-proportional representation
Field selection (random, stratified, etc.)
Within-field methodology
Disease assessment scales
Sample size
Sampling procedure
Data encoding
Crop phenology codes
Database management system
Yield loss estimation methods

Methodology for conducting integrated pest (insect, disease, weed) surveys, i.e. surveys to estimate pest intensity and losses, is currently being developed and tested by IRRl (Elazegui *et al.*, 1988), and a field manual will be published in the near future.

Table 1 Rice disease losses reported in the International Rice Research Newsletter (IRRN), 1976 to present

Disease	Month/Season/Year	Place/Country	Yield loss report	Reference
Blast Sheath blight Bacterial blight Grassy stunt	1975	Rice-growing countries	Blast was estimated to cause losses of more than US$8 million in each of three countries: Taiwan, Iran, and Mexico. Sheath blight also caused about the same loss in South Korea and Taiwan. Bacterial blight was estimated to cause an everage loss of 4% in Bangladesh, which amounted to about US$96 million. In Indonesia, grassy stunt virus caused more than US$20 million in crop losses.	Rice disease survey: 1975 H.E. Kauffman IRRN 5:8-9 Oct 1977
Ragged stunt	October 1977	Chachengsao, Thailand	About 3,200 ha of RD7 in Chachengsao province, central plains region, were severely infected; in many fields, 90% of the plants failed to produce normal panicles. Average yields were about 0.4 t/ha; however, the resistant variety RD9 and some traditional tall varieties grown in the area yielded normally.	Ragged stunt disease in Thailand Praphas Weerapat IRRN 3(1): 11-12 Feb 1978
	February 1978	Paddy Breeding Station, Coimbatore, India	Yield losses ranged from 80 to 100%.	Rice ragged stunt disease in India R. Velusamy, M. Balasubramanian, and P.O. Subba Rao IRRN 4(1): 4-5 Feb 1979
Sheath rot	Late Kharif, 1978-79	Nellore, India	Sheath rot has been known to cause up to 85% loss in yield.	Outbreak of sheath rot on rice K. Muralidharan and G. Venkata Rao IRRN 5(5): 7-8 Oct 1980
	Kharif, 1982	Punjab, India	Sheath rot caused losses up to 50%.	Sheath rot in the Punjab, India M.S. Kang and G.S. Rattan IRRN 8(3): 7-8 June 1983
Bacterial blight	Kharif, 1980	Punjab, India	Bacterial blight assumed an epiphytotic form and caused considerable yield loss throughout the state, in some areas as high as 60-70%.	Rice bacterial blight status in the Punjab, India G.L. Raina, G.S. Sidhu, and P.K. Saini IRRN 6(5): 12 Oct 1981
	Kharif, 1980-81	India	Bacterial blight infection has been moderate to severe in many states since 1980, and occurred in epidemic proportions in almost all of the Punjab in 1980 and 1981 Kharif. Losses generally were 15-20% and sometimes rose to 40%.	Rice disease status in India R.K. Upadhyay IRRN 10(5): 17-18 Oct 1985

We examined reports of field losses published in the IRRN from 1981 to the present and some examples of losses in tropical rice are shown in Table 1.

Concluding remarks

A recent workshop at IRRI concluded that there is a need to develop improved methods for assessing rice losses, because there is a demand by policy-makers for loss estimates (IRRI, 1988). At the same workshop, Teng *et al.* (1988) reviewed current knowledge on crop losses in tropical rice, and concluded that most estimates were too general and unsystematic for guiding decisions at the national or local levels. For example, no dataset that we know of has been able to answer the question of whether losses due to specific diseases have changed in the same area over time. We feel that this type of loss estimate is necessary to help rice scientists anticipate changes in productivity in the future, and to develop disease management strategies that will contribute to sustained and stable yields.

To this end, *we urge the creation of a network of cooperating rice pathologists in tropical Asia to improve methodology and collection of loss estimates.* This network should have a finite schedule, e.g. five years, to arrive at comparative loss data for specific rice environments such as irrigated, rainfed upland, rainfed lowland and deepwater. The network should include crops grown in the extended rice farming system, and use different approaches for collecting crop yield and loss data. It should also include, apart from national program scientists in Asia, scientists from IRRI and resource persons from centers of crop loss expertise in developed countries.

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Discussion

Mamluk, O.F. (ICARDA): Does the method for yield loss assessment apply to only one variety?

Answer: No, I showed data on one variety. This illustrates the useful feature of using a crop model as a basis for estimating the yield loss. In the field, the major problem is to be able to develop a single assessment model that can be used in many environments and for many varieties. By using a single crop model, environmental data must be run (maximum and minimum temperature, solar radiation, rainfall, etc.). The model also requires genetic information, i.e. genetic coefficients which are variety-specific. Within the system there is a data file which contains most of the major varieties (rice, corn, etc.) as well as the main genetic coefficients, which accounts for the varietal differences.

Nagarajan, S. (India): The estimation of loss involves two components, namely conducting the surveys and estimating the disease loss. Are you satisfied with these survey procedures? Is it necessary to systematize the acquisition of the so-called "reliable sample"?

Answer: I am not fully satisfied with the survey procedures. The persons in charge of loss assessment are different from those in charge of pest surveillance in the field and often they do not communicate with each other. To obtain information on loss estimate, assessment methodology, sampling methodology, disease-loss relationship and means of integrating the information are required along with field surveys including sample points from farmers' fields. As the field survey methodology is not sufficiently developed, IRRI initiated research on integrated pest survey to look specifically into a method for field surveys. I would like to emphasize that computers are not essential for loss estimation, although they may speed up the work.

John, V.T. (IITA): 1. You referred to the use of fungicides as a tool to estimate disease loss. However, fungicide control is not always effective , in particular for a crop like rice. The onset of the disease may be delayed or the disease may be eliminated to some extent only. 2. I am not satisfied with the non-replicated plot approach you adopted for the estimation of disease loss. This may not be suitable from the statistical point of view.

Answer: 1. There are problems with the use of fungicides to generate epidemics, in particular in foliar diseases. When using a fungicide, in a disease loss experiment, it is imperative to determine whether the fungicide does not have a phytotonic or phytotoxic effect. Complete control by a fungicide can be achieved by understanding the epidemiology of the disease, in other words by the intelligent use of the fungicides. Regarding alternative methods, the use of isogenic lines is being gradually abandoned presently. 2. The use of non replicated experiments to generate data for disease loss modeling was discussed at a workshop on "Crop Loss Assessment to Improve Pest Management in Rice and Rice-Based Farming Systems in South and South-East Asia" which was held at IRRI in October 1987. This issue was raised and among the participants in this meeting, Dr. K. Gomez (IRRI) pointed out that this approach was statistically acceptable, particularly in the case of response surface methodology which involves no replications or incomplete replications. However, a large number of treatment points is required to obtain a relationship between disease or insect and yield loss.