Terms and Concepts for Yield, Crop Loss, and Disease Thresholds

FORREST W. NUTTER, JR., Associate Professor, Department of Plant Pathology, 351 Bessey Hall, Iowa State University, Ames 50011; PAUL S. TENG, Coordinator for PPM, International Rice Research Institute, Box 933, Manila, Philippines; and MATTHEW H. ROYER, Chief Operations Officer, Biological Assessment and Taxonomic Support, APHIS-PPQ-OS, USDA, 6505 Belcrest Road, Hyattsville, MD 20782

The initial report (14) of a subcommittee of the APS Plant Disease Losses Committee dealt with terms and concepts relating to the measurement of disease intensity to obtain accurate and precise quantitative information on the relationship between disease intensity (stimulus $= X$) and yield or yield loss (response $= Y$). In addition to standardizing the terms and concepts for the measurement of disease intensity, members of the full committee identified a need to clarify and standardize terms and concepts pertaining to yield, crop loss, and disease thresholds. A second subcommittee was formed to accomplish this task. This report describes concepts concerning reference points for yield and crop loss as well as a hierarchy for threshold terms, then presents a list of terms and definitions to standardize terminology for crop loss assessment.

Reference Points for Assessing Yield and Crop Loss

Estimates of loss are a prerequisite to the rational development of any agricultural research program that has plant protection as a component (1,6,9,17,20,23). Reliable estimates of loss facilitate the objective identification of the relative importance of biotic pests (2,3,7,10,15). Consequently, limited resources (federal, state, or private) can be assigned on a priority basis to optimize returns from a given effort. Accurate information concerning losses is also needed by growers and plant protection specialists to develop decision thresholds for determining when cost-effective control measures should be deployed (7,14,22). The need for reliable crop loss assessment methodology (to develop reliable decision aids) assumes added importance given the current worldwide concern about improving or maintaining environmental quality by reducing the use of pesticides (18).

Several reference points for yield must be characterized before plant protection programs can be prioritized according to need (Fig. 1). "Maximum attainable yield" is the theoretical yield that could be achieved if the crop was grown under optimum environmental conditions, along with the use of all available crop protection tactics to also alleviate the effects of biotic pests. Genetic yield potential—not biotic pests or environment—is the primary factor that limits the maximum attainable yield. "Attainable yield" is the yield obtained at a specific location when all available crop protection tactics are used to alleviate the stresses caused by biotic pests. Thus, attainable yield is site-specific and is the yield obtained when biotic pests are alleviated but environmental (abiotic) factors such as soil fertility, water availability, growing degree days, etc., may still be limiting yield. Attainable yields are commonly achieved in well-managed experimental plots.

The cost of deploying all available pest management tactics to achieve attainable yield may be higher than the return expected from the sale of the crop and/or may harm the environment because of excessive inputs. In contrast, "economic yield" is the achievable yield that provides the highest net return on expenditure. If the cost of utilizing a new disease management technology exceeds the expected return, the technology is not likely to be adopted. "Actual yield" is the production level achieved when producers utilize pest management programs currently recommended for a crop or cropping system, yet several factors (environment, weeds, diseases, insects) are still limiting yield. The difference between actual and attainable yield is the method used by the Food and Agriculture Organization (FAO) to report crop losses (4). Most, if not all, pest management practices are aimed at closing the gap between actual and attainable yield. In a PLANT DISEASE editorial, Cook (5) eloquently argued against the use of the term "crop loss." He described a situation in which a grower achieved a yield of 90 bu/acre (grower yield), while replicate plots in the same field fumigated with Telone C to eliminate *Pythium* spp. and parasitic nematodes yielded 128 bu/acre (attainable yield). By FAO's definition, this difference in yield is an estimate of crop loss and represents measurable constraints to production. This estimate of loss corresponds to the as yet unavoidable losses caused by plant pests and pathogens. If these constraints were alleviated, the plant genotypes would realize yields closer to attainable levels. Thus, "crop loss" is a function of one or more biotic factors, each of which may be contributing to a reduction in yield, whereas "yield loss" is the reduction in yield caused by a single pathogen or pest.

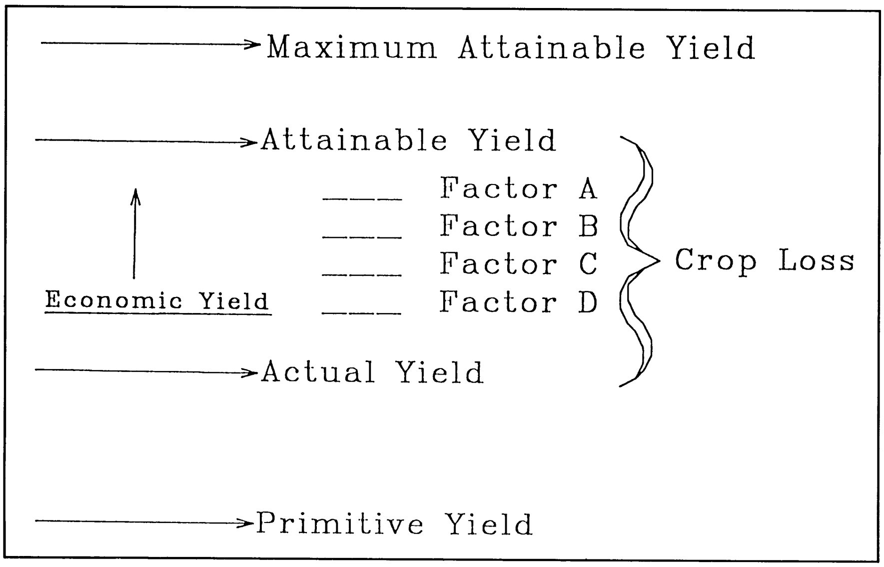

Fig. 1. Reference points for crop loss assessment.

Journal Paper No. J-14955 of the Iowa Agricultural and Home Economics Experiment Station, Ames. Project No. 3116.

Accepted for publication 9 September 1992.

"Primitive yield" is the yield achieved when no disease or pest control tactics are utilized. The difference between primitive yield and actual yield represents improvements in crop protection presently achieved by the deployment of accepted pest management practices. For example, in the southeastern United States, peanuts grown in the absence of any fungicide commonly yield 40–70% less than peanuts managed with fungicides to control foliar diseases. The use of fungicides has helped to increase the actual yield realized by growers, thereby closing the gap between actual and attainable yield. Soilborne pathogens, however, continue to limit production levels achieved by growers. These pathogens, coupled with the effects of weeds, insects, and nematodes, continue to cause a gap between actual yield and attainable yield, although the magnitude of this gap fluctuates from year to year.

Terms and Concepts for Crop Loss

"Crop injury" is defined as the visible or measurable symptoms and/or signs caused by plant pathogens or pests, and "crop damage" is defined as any reduction in the quantity and/or quality of yield that results from crop injury (20). Plant pathology evolved into its own science not because plant pathogens cause injury, but because injury often results in damage and damage results in loss of revenue or direct loss of a food source (9,12,19,20,24). Injury (disease intensity) can often be measured quantitatively by specific units of measure (dimensions). For example, disease incidence has the dimensions N/N, since incidence is defined as the number of infected sample units divided by the total number of sample units assessed (14). Disease severity may have the dimensions N/L^2 (number of lesions per unit leaf area), N/N (number of lesions per number of units sample), or L^2/L^2 (visible diseased leaf area/total leaf area).

As an alternative to measuring disease intensity to analyze disease and pest-induced losses, several researchers have proposed that the integrals of healthy (green) leaf area duration or healthy (green) leaf area index (square meters of green leaf tissue per square meter of land) would have a better relationship to yield (8,11,21). Nutter (11) found a good relationship between green leaf area index (GLAI) and yield in several crops and that a hand-held, multispectral radiometer could be used to accurately and rapidly estimate GLAI. Solar "radiation interception" (magejoules per square meter by green leaf area) and "radiation use efficiency" (grams per megajoule) are variables used in crop growth simulation models to account for the effects of pathogens and pests on crop growth and yield. Radiation interception generally is a function of GLAI.

In addition to injury, damage must also be measured quantitatively if we are to establish quantitative relationships between injury (X) and damage (Y). For example, the yield or yield loss response (damage) may be measured as a reduction in volume per unit area harvested (bu/acre = L^3/L^2), by a reduction in mass per unit area harvested (kg/ha = N/L^2), and/or by changes in quality, such as increased protein content in barley (% protein = $N/N \times 100$) or reduced oil content in soybeans (% oil = $N/N \times 100$). The development and use of precise and accurate measurements of X and Y, coupled with information concerning the value of the crop ($/bu, $/lb, etc.) provides a means for researchers to develop a number of reference thresholds for improved decision making to better manage plant pathogens and pests (16–18). Thus a chain of quantitative information is needed along with appropriate linkages: injury—damage—monetary loss—economic damage threshold.

These linkages are needed because injury data per se are insufficient to develop thresholds. Injury is not the same thing as damage. Injury (X) assessed at time (T) must be interpreted to project damage at some future point in time (usually harvest). This linkage (equation) is known as the "damage function." The partial regression coefficient (slope of the equation) that relates injury to damage is known as the "damage coefficient." There may be more than one damage coefficient if injury affects quality as well as quantity of yield. For example, barley spot blotch, caused by *Cochliobolus sativus*, has been shown to reduce not only yield quantity (bu/acre) but also malting quality by increasing protein content and by decreasing kernel plumpness (13). Barley protein content in excess of 13.5% (dry weight basis) is heavily discounted or rejected for use by maltsters (22). High protein is undesirable because high-protein barley germinates unevenly and tends to require longer steeping time. A reduction in the percentage of plump kernels (weight of kernels remaining on a 2.38 mm × 1.91 cm slotted sieve after shaking for 30 sec per total weight of the sample × 100) may also be discounted at the buying point. The damage coefficients for reduced barley yield quantity, increased protein content, and reduced percent plump kernels as affected by spot blotch severity are: yield reduction (bu/acre) = −32.4 (disease severity), protein content (%) = +1.02 (disease severity), and percent plump kernels = −39.0 (disease severity). Although there is a linear relationship between injury and damage in these examples, the relationship between injury and damage may or may not be linear for other pests and crops.

The next linkage point is the "loss function," which relates damage to loss in monetary terms if the crop is to be sold. Before monetary loss can be estimated, the amount of damage must be multiplied by a price factor. Because the prices of commodities are variable, the expected price may be used in calculations or a risk-rated system can be used in which probabilities are assigned worst-case and best-case price scenarios. For example, a "median" rating is assigned to the midpoint of prices that divides all possible outcomes. One-half of all possible outcomes should fall below the median value and one-half should be above. Thus, there would be one chance in two of a price better than the median outcome and an equal chance of a less favorable outcome. A "worst" rating is assigned to unfavorable prices that would be experienced only about once in 40–50 years of farming. A "pessimistic" rating is assigned to unfavorable outcome at the one-sixth probability level. Thus, there would be one chance in six of an outcome as bad or worse than the pessimistic rated level. The pessimistic rating should be about halfway between the median and the worst rating. A "best" rating is assigned to favorable prices that would be exceeded only about once in 40–50 years of farming. An "optimistic" rating is assigned to favorable outcomes at the one-sixth probability level.

For the sake of simplicity, let us assume that the median price for barley is $3.00/bu and that best, optimistic, pessimistic, and worst prices are $4.00, $3.50, $2.50, and $2.00/bu, respectively. When these price coefficients are combined with the damage coefficient (−32.4), the monetary loss per acre, as affected by price, can be determined (Fig. 2). It is evident that the price coefficient greatly affects monetary loss and, therefore, also greatly affects the economic damage threshold. Loss functions for damage in terms of quality can also be included to improve estimates of the direct losses caused by plant pathogens and pests. For example, the price per bushel for malting barley decreases by 1.3¢ for each one-tenth increase in protein. Should disease injury result in protein levels above 13.5%, the barley crop may be rejected for use by the malting industry and the price per bushel could fall to the level paid for feed barley. Moreover, each 1% decrease in the percentage of plump kernels also reduces the price per bushel by an additional 1.6¢. Thus, several loss functions may exist, and these should be considered when attempting to determine the total monetary loss from damage. This information will directly affect the development of economic damage thresholds.

Threshold Terms and Concepts

Without quantitative information, it would not be possible to develop thresholds for use in plant protection programs

(7,16,17,23,24). Quantitative units of measure provide a means for researchers to develop thresholds that can be used to help producers make more prudent disease and pest management decisions. In a hierarchy of thresholds (Fig. 3), the "perception (detection) threshold" is defined as the lowest pathogen or pest population density or injury level needed to detect a pathogen or pest. Sample design (random, regular, stratified random, sequential, etc.), sampling pattern (X, W, diamond, etc.), and sample size as well as distribution of the pathogen or pest in the crop affect the detection threshold. If an entire population of plants (a census) were inspected for the presence of a disease, then even a single lesion may be detected. However, inspecting every plant in a population of plants is rarely practical. Therefore, a sampling protocol must be developed with the resolution to detect a level of the pathogen or pest that is below the "warning threshold," which is the pathogen or pest density or injury level below the "action threshold" and alerts a grower to prepare for action. The action threshold is the pathogen or pest density or injury level at which action must be taken to prevent the pathogen or pest population from exceeding the "damage threshold," which is the lowest pathogen or pest or injury level at which some damage is projected. The action taken to prevent a pathogen or pest population from exceeding the damage threshold often costs the grower, and this amount of money is converted to its equivalent amount of damage and added to the damage threshold to determine the "economic damage threshold." For example, if the cost of aerial application of a fungicide to barley is $15.00/acre,

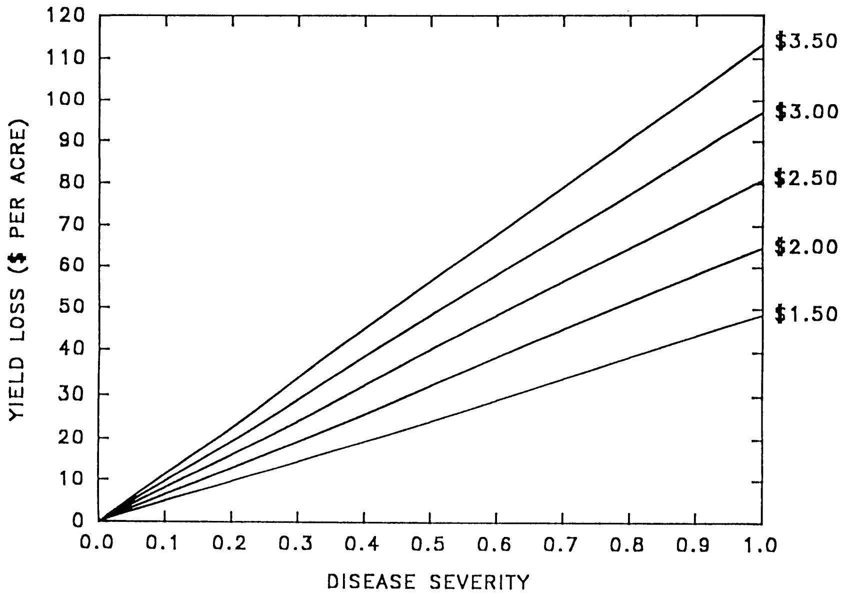

Fig. 2. Effect of barley price ($/bu) and level of disease severity on yield loss ($/acre).

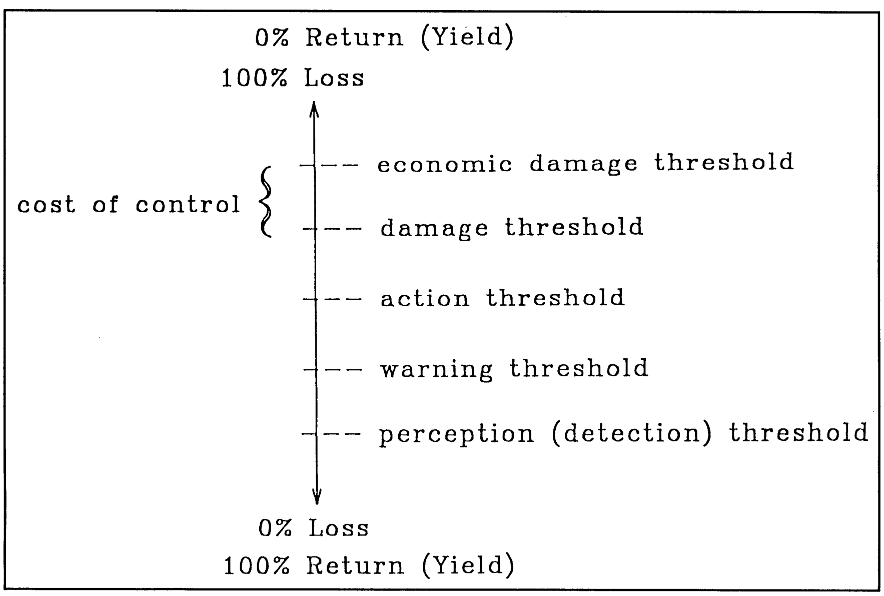

Fig. 3. Hierarchy of thresholds for decision making.

the economic damage threshold would be the amount of injury causing $15.00 damage per acre. If the price per bushel of barley is $1.50, this would be an injury (disease severity) level of approximately 0.35 or 35% (Fig. 2). If the price per bushel of barley is $4.00, the economic damage threshold would be approximately 0.15 or 15%. Since decision thresholds are based on both injury and price, we prefer the term "economic damage threshold" to "economic injury threshold."

Damage thresholds are rarely static and are often affected by the "expected yield," which is an estimate of the anticipated level of production made by the grower or farm manager (22). Zadoks (23) described the use of "sliding" damage thresholds for wheat as affected by various pathogens and pests. In general, damage threshold values increase as a crop approaches maturity. Thus, as the growing season progresses, the amount of injury required to cause economic damage also increases. Zadoks (23) also noted that soil type (and other abiotic factors) can affect damage thresholds. If quality is an important factor affecting price, as with most fruits and vegetables, then the damage threshold on these crops may be close to zero.

Terms and Definitions

Our subcommittee was appointed to draft a list of terms and definitions pertaining to yield, crop loss, and disease thresholds. The first draft was distributed to committee members at the 1988 annual meeting of APS. Suggestions from the full committee were incorporated into a second draft that was distributed to committee members at the 1990 annual meeting. Final comments and suggestions of committee members were then incorporated into the terms and definitions listed here.

critical level: lowest level of disease injury (or pest intensity) that, when exceeded, results in yield loss (= damage threshold); it is sometimes possible to empirically establish, under a well-defined set of experimental conditions, the minimum injury or pest intensity levels that will result in crop damage (*see also* threshold, damage)

crop: population of plants grown to provide food, fiber, medicinals, seed, fuel, or other products

crop damage: any reduction in the quantity and/or quality of yield that results from injury

crop injury: visible or measurable symptoms and/or signs caused by pathogens or pests

crop loss: a reduction in value and/or financial return due to damage; often measured as the difference between actual yield and attainable yield due to the effects of one or more pathogens or pests (*see also* loss data, yield; loss data, crop)

damage coefficient: the partial regression coefficient relating injury level (X) to damage level (Y) (*see also* damage function; loss, function)

damage function: an equation relating injury (or pathogen or pest population density) to yield or yield loss during a specific period of crop development

economic injury level: classic definition coined by entomologists to describe the level of pest attack at which the benefit of control just exceeds its costs; the phytopathological equivalent is economic damage threshold (*see also* threshold, economic damage)

harvest index: proportion of crop biomass that composes a commodity (e.g., grain, tuber, fruit) in relation to the total biomass of a crop

loss, actual: measured losses that have already occurred and may still be occurring and may be divided into direct and indirect losses

loss, consumer's: the losses realized by the consumer as price increases in commodities as a result of direct and indirect (actual) losses occurring at the grower level and/or during processing, storage, transport, and marketing

loss, crop: *see* crop loss

loss, direct: the losses in quality and quantity of product sustained by the grower, including costs expended for disease and/or pest management practices; direct losses may be partitioned into primary and secondary losses (*see also* loss, indirect; loss, primary; loss, secondary)

loss, economic: the difference in financial return between maximum economic yield and actual yield

loss, exporter's: produce rendered nonsalable, usually in bulk product, due to injury or contamination by pathogens (or pests) or their products (e.g., aflatoxins)

loss, farmer's: losses occurring at the grower level; loss of food, income, or capital that impoverishes growers, which may include the cost of disease (or pest) prevention and/or management practices

loss, function: an equation used to estimate monetary loss from damage (*see also* damage function)

loss, hidden: the extent to which a "normal" crop falls short of its attainable yield or return on investment (e.g., early season injury by diseases [or pests] may result in the production of subsequently smaller leaves [reduced radiation interception] and therefore lower yields)

loss, indirect: losses arising from the increased cost of handling, storage, processing, and/or transport sustained by various parties as a direct consequence of plant pathogens (or pests); these parties include the farm operator, rural community, exporters, trade for wholesale and retail dealers, governments, and consumers

loss, postharvest: losses resulting from crop damage occurring after the crop is gathered from the production site, i.e., damage occurring during transport, storage, processing, and/or marketing of the salable product

loss, potential: regional or site-specific crop losses that may occur in the absence of effective control measures; the difference between attainable yield and primitive yield

loss, preharvest: losses resulting from crop damage occurring before the crop is gathered from the production site

loss, primary: preharvest and postharvest losses of plant products due to plant diseases (and pests), excluding costs associated with the deployment of disease (and pest) management practices

loss, production: the reduction in units of yield (bushel, kilogram, ton, etc.) for a defined geographic area (county, state, region) based on knowledge of the mean percent yield loss (or loss proportion) for a particular pathogen or pest as determined by the equation: production loss = [actual yield (of a geographic area) divided by (1.0 − loss proportion)] minus the actual yield of the geographic area

loss, regular: an estimation of the level of losses occurring each season over a specified period of time

loss, rural community: the economic life of the rural community and its dependent industries as affected by reduction in crop yield and quality (e.g., as invested capital decreases, unemployment increases)

loss, secondary: losses caused by a reduction in the yielding capacity of future crops (cumulative effect of soilborne, seedborne, or tuber-borne diseases in annual crops, premature defoliation or reduced vigor in perennials) sustained at the grower level; this includes the costs associated with the deployment of disease (and pest) management practices as well as loss of capital invested in soil, seed, renovation propagation, etc.

loss, state: government costs to maintain plant protection services, education and research institutions, and extension services and subsidies to ensure fair income to the grower and to stabilize prices, including loss in tax revenue due to reductions in plant products caused by diseases (and pests)

loss, structural: losses that are unavoidable in a given agroecosystem, such as the cost of using resistant germ plasm, crop rotation, etc.

loss, theoretical: the difference between maximum attainable yield and actual yield

loss, transitional: losses that occur when growers change over from one farming system to another; restricted to loss of income or interest (*see also* loss, structural)

loss, yield: the difference between actual yield and attainable yield for a single pest (*see also* crop loss)

loss data, crop: data sets documenting and quantifying the relationships between one or more pathogens (or pests) and the crop losses they cause (*see also* loss data, yield)

loss data, yield: data sets that document and quantify the effects of a single pathogen (or pest) on yield (*see also* loss data, crop)

maximum genetic yield potential: *see* theoretical yield potential; yield, maximum attainable

net crop growth rate: amount of crop biomass produced per square meter per day; often measured as a function of radiation use efficiency and radiation interception

radiation interception: amount of solar radiation captured by the photosynthetic surface of a crop within a defined unit area, commonly expressed as $MJ/m^2/day$

radiation use efficiency: amount of crop biomass produced per unit of intercepted solar radiation, usually expressed as g/MJ

theoretical yield potential: the maximum yield obtainable when the level of biotic stresses due to pathogens (or pests) equals zero; usually taken as the y-intercept calculated from regression equations relating increasing injury (or pest) levels (X) with yield response (Y)

threshold, action: the pathogen (or pest) population density or injury level at which action must be taken to prevent the pathogen (or pest) population from exceeding the damage threshold

threshold, damage: the lowest pathogen (or pest) population density or injury level for which at least some damage is projected (*see also* critical level)

threshold, detection: the minimum pathogen (or pest) population density or injury level required for a disease or pest to be detected in a crop; this threshold is affected by sampling procedures (pattern, number, distribution of pathogens and pests, etc.)

threshold, economic: generic term for the concept whereby damage levels (estimated from injury) are used in making cost-efficient disease management decisions

threshold, economic damage: the lowest disease (or pest) population density or injury level that will cause the damage threshold to be exceeded by an amount equal to the cost of disease (or pest) control measures; the concept has been applied primarily where management tactics are responsive rather than preventative

threshold, perception: *see* threshold, detection

threshold, warning: the pathogen (or pest) population density or injury level that is below the action threshold and warns a grower to prepare to act on the action threshold

tolerance, disease: a measure of the relative yield response of two or more host genotypes to increasing injury levels caused by diseases (*see also* tolerance, pathogen or pest)

tolerance, pathogen or pest: a measure of the relative yield response of two or more host genotypes to increasing pathogen (or pest) population density levels (*see also* tolerance, disease)

yield: the measurable product of a crop

yield, actual: the site-specific yield obtained when crops are grown using current production practices at the farm level

yield, attainable: the site-specific yield obtained when crops are grown using all available pest control technologies to minimize biotic stress, i.e., a measure of the genetic potential of a crop genotype at a specific site (*see also* yield, maximum attainable)

yield compensation: the phenomenon whereby injury to individuals in a population is compensated for by an increased yield response in adjacent healthy plants

yield components: characterization of the individual plant parts that directly contribute to yield based on frequency, size, and/or weight (e.g., in barley: [number of spikes/unit area] × [number of kernels/spike] × [average kernel weight])

yield, economic: the yield level that optimizes the input/output ratio involving production costs (including expenditures for disease and pest management practices) vs. financial return (yield improvement × price)

yield, expected: estimate of the anticipated level of production for a particular field made by the grower or farm manager based on field histories and local growing conditions (weather, diseases, pests, etc.)

yield, gap: the quantitative difference between actual yield and attainable yield as affected by varietal and environmental influences; a measure of crop loss

yield, maximum attainable: the yield obtained when crops are grown under optimal environmental conditions using all available production and pest control technologies to optimize yield; thus, the crop genotype is the limiting factor on yield production (*see also* yield, attainable)

yield, maximum economic: the yield based on optimization of the input/output ratio that gives the highest financial returns on expenditures (= economic yield)

yield, primitive: the yield of land races in subsistence agriculture; sometimes defined as the yield obtained when no disease (or pest) control tactics are employed (i.e., a nontreated control)

yield, reference: the average yield of a crop inclusive of all production constraints for a given region (usually reported in units of yield per unit crop area)

yield, theoretical: the yield obtained under the best growing conditions according to calculations based on plant and crop physiology or the maximum theoretical yield as determined by using crop growth simulation models

We acknowledge the following for their comments and suggestions in compiling this special report: Richard D. Berger, Kira L. Bowen, C. Lee Campbell, Vern J. Elliott, Merle G. Eversmeyer, Charles S. Johnson, Kenneth B. Johnson, David R. MacKenzie, Wayne L. Pedersen, Alan P. Roelfs, Fred M. Shokes, and Donald H. Smith. The Plant Disease Losses Committee invites comments and suggestions concerning this special report.

LITERATURE CITED

1. Campbell, C. L., and Madden, L. V. 1990. Introduction to Plant Disease Epidemiology. John Wiley & Sons, New York.
2. Carlson, G. A. 1971. Economic aspects of crop loss control at the farm level. Pages 2.3/1-2.3/6 in: Crop Loss Assessment Methods. L. Chiarappa, ed. FAO, Rome.
3. Carlson, G. A., and Main, C. E. 1976. Economics of disease-loss management. Annu. Rev. Phytopathol. 14:381-403.
4. Chiarappa, L., ed. 1981. Crop Loss Assessment Methods. Suppl. 3. FAO Commonwealth Agricultural Bureaux, Farnham Royal, United Kingdom.
5. Cook, R. J. 1985. Use of the term "crop loss." Plant Dis. 69:95.
6. Gaunt, R. E. 1987. A mechanistic approach to yield loss assessment based on crop physiology. Pages 150-159 in: Crop Loss Assessment and Pest Management. P. S. Teng, ed. American Phytopathological Society, St. Paul, MN.
7. James, W. C., and Teng, P. S. 1979. The quantification of production constraints associated with plant diseases. Pages 201-267 in: Applied Biology. Vol. 4. T. H. Coakey, ed. Academic Press, New York.
8. Johnson, K. B. 1987. Defoliation, disease, and growth: A reply. Phytopathology 77:1495-1497.
9. Main, C. E. 1977. Crop destruction—The raison d'etre of plant pathology. Pages 55-78 in: Plant Disease. Vol. 1, How Disease Is Managed. J. G. Horsfall and E. B. Cowling, eds. Academic Press, New York.
10. Mumford, J. D., and Norton, G. A. 1984. Economics of decision making in pest management. Annu. Rev. Entomol. 29:157-174.
11. Nutter, F. W., Jr. 1990. Remote sensing and image analysis for crop loss assessment. Pages 93-105 in: Crop Loss Assessment in Rice. International Rice Research Institute, Manila, Philippines.
12. Nutter, F. W., Jr. 1991. Assessing the benefits associated with planned introductions of genetically engineered organisms. Phytopathology 81:344-348.
13. Nutter, F. W., Jr., Pederson, V. D., and Pyler, R. E. 1985. Effect of spot blotch (*Cochliobolus sativus*) on the quality and yield of malting barley. Brew. Dig. 59:24-28.
14. Nutter, F. W., Jr., Teng, P. S., and Shokes, F. M. 1991. Disease assessment terms and concepts. Plant Dis. 75:1187-1188.
15. Ordish, G., and Dufour, D. 1969. Economic basis for protection against plant diseases. Annu. Rev. Phytopathol. 7:31-50.
16. Pedigo, L. P., Hutchins, S. H., and Higley, L. G. 1986. Economic injury levels in theory and practice. Annu. Rev. Entomol. 31:341-368.
17. Stern, V. M. 1973. Economic thresholds. Annu. Rev. Entomol. 18:259-280.
18. Stern, V. M., Smith, R. F., van den Bosch, R., and Hagan, K. S. 1959. The integrated control concept. Hilgardia 29:81-101.
19. Teng, P. S. 1985. Construction of predictive models II. Forecasting crop losses. Pages 179-206 in: Advances in Plant Pathology. Vol. 3, Mathematical Modeling of Crop Disease. C. A. Gilligan, ed. Academic Press, London.
20. Teng, P. S., and Johnson, K. B. 1988. Analysis of epidemiological components in yield loss assessment. Pages 179-189 in: Experimental Techniques in Plant Disease Epidemiology. J. Kranz and J. Rotem, eds. Springer-Verlag, New York.
21. Waggoner, P. E., and Berger, R. D. 1987. Defoliation, disease, and growth. Phytopathology 77:393-398.
22. Wilson, W. W. 1983. Price/quality relationships in the malting barley market. N.D. State Univ. Agric. Exp. Stn. Agric. Econ. Rep. 83003.
23. Zadoks, J. C. 1985. On the conceptual basis of crop loss assessment: The threshold theory. Annu. Rev. Phytopathol. 23:455-473.
24. Zadoks, J. C., and Schein, R. D. 1979. Epidemiology and Plant Disease Management. Oxford University Press, New York.

Salute to APS Sustaining Associates

This section is designed to help APS members understand more about APS Sustaining Associates. Information is supplied by company representatives. Each month features different companies. A complete listing appears in each issue of *Phytopathology*.

Rhone-Poulenc Ag Company. Contact: Valerie Wolford, P.O. Box 12014, Research Triangle Park, NC 27709; 919/549-2243. Rhone-Poulenc is a rapidly growing company engaged in the discovery, manufacturing, and marketing of crop protection chemicals. It is the U.S. affiliate of Rhone-Poulenc S.A., the largest chemical manufacturer in France and among the 10 largest chemical groups in the world. Current products include the fungicides Aliette, Rovral, and Chipco 26019; herbicides Ronstar, Asulox, Buctril, Weedar, and Weedar 2,4-D; plant growth regulators Cerone, Ethrel, Prep, and Florel; insecticides-nematicides Larvin, Mocap, Sevin, Temik, and Zolone; and the defoliant Folex. Aliette is a systemic material capable of providing bidirectional translocation in the plant. It is active primarily against Phycomycetes (downy mildew, *Phytophthora*, and *Pythium* species). Rovral (Chipco 26019) is a broad-spectrum fungicide that provides control of *Alternaria, Botrytis, Helminthosporium, Monilinia, Rhizoctonia, Sclerotinia, Aspergillus, Penicillium, Rhizopus,* and *Mucor.*

Ricerca, Inc. Contact: Suzan H. Woodhead, 7528 Auburn Road, Painesville, OH 44077-1000; 216/357-3752. Ricerca, Inc., is a broad-based technology company that provides R&D services on a contract basis to clients in the agricultural and chemical industries. More than 200 scientists and support personnel help clients to develop new products, improve existing products, and support the registration of products in compliance with good laboratory practices. The Plant Disease Control Group has the expertise and facilities for large-volume primary screening and advanced testing of chemicals against more than 30 diseases and several nematode species. Specialty studies such as rain tenacity evaluations and wood preservative assays are available. The Biocontrol Group conducts discovery, development, toxicology, and formulations research leading to the registration of biocontrol agents of plant diseases, weeds, and insects. The Biological Evaluations Group offers herbicide and insecticide screening and Subdivision J studies.

RJR Nabisco, Inc. Contact: Gary M. Hellmann, Bowman Gray Technical Center, 1100 Reynolds Boulevard, Winston-Salem, NC 27102; 919/741-0735. RJR Nabisco, Inc., is one of the world's leading consumer packaged goods companies, with major interests in tobacco and food products. As one of the world's largest processors of agricultural products, RJR Nabisco's subsidiaries produce more than 100 leading brands in 29 product categories. It has worldwide manufacturing operations and markets its products in more than 100 countries. For many years, the company has provided substantial support and funding for agricultural and educational programs, including major research and extension efforts designed to develop technology and enhance strategies for increased disease control in plants.

Rogers NK Seed Company. Contact: Wayne L. Wiebe, 21435 Road 98, Woodland, CA 95695; 916/666-0986. On January 1, 1991, Rogers Brothers Seed Company and Northrup King Vegetable Division merged to form one company. Over the past 100 years each company has developed into a leader in its respective vegetable seed lines. Rogers NK Seed Company, which combines Rogers large seed line with Northrup King's small seed line, is one of the largest full-line vegetable seed companies in North America. Rogers NK Seed Company has a strong commitment to research. The goal of its research is to develop, produce, and market improved agronomic and vegetable crop cultivars. To help achieve these goals, the company has research stations throughout the United States, as well as in Canada, Mexico, South America, and Europe.

Rogers NK Seed Company. Contact: Paul Moser, Research Center, 6338 Highway 20-26, Nampa, ID 83687; 208/466-0319. On January 1, 1991, Rogers Brothers Seed Company and the vegetable seed division of Northrup King merged to form Rogers NK Seed Company, a full-line vegetable seed company that supplies seed to the processing, fresh market, and garden seed industries. The major research emphasis is development of new varieties and improvement of existing strains. Research at Rogers NK has top priority; its main goal is to increase the productivity, quality, and reliability of crops for the benefit of the consumer, farmer, and processor. Plant pathology and its application to disease control are important to its success. Rogers NK is a member of the Sandoz Seeds group.