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CROP LOSS ASSESSMENT AND ECONOMIC INJURY LEVELS

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Introduction

Crop losses caused by pests and diseases are well documented, but the additional yield loss that may be Bexpected at a particular disease severity or pest density is generally not well documented (Wood & Jellis, 1984). How various pests and diseases affect growth and production under various conditions is, in general, also not known. Estimates of yield loss due to pests or diseases are needed in any supervised or integrated control system. They constitute the basis for an economic cost-benefit analysis of control measures and thus help to develop rational crop protection systems. These yield losses may be expressed in kg product or economic value. Yield losses are often based on intelligent guesses by agronomists and crop protectionists; seldom are they based on knowledge of the nature and level of crop growth reduction due to the presence of pests and diseases (hereafter collectively referred to as pests). The increasing importance of pests as growth and production reducing factors (Smith et al., 1984) justifies more detailed analysis of the interaction between the host plant (crop) and its enemies. This may be a statistical analysis of the relation in physical terms or in economic value between pest severity or infection level and crop loss. Much detailed and painstaking observation of pests amd crop growth is required to determine growth and yield reductions due to their effects. In most studies of pest management the concept of Economic Injury Level (EIL) is introduced as the value at which the costs for control are in balance with the expected yield loss. Usually, control measures are needed long before this level is reached. Such an action threshold is widely used. However, the EIL concept, although revolutionary when it was introduced by Stern (1959), presumes a fixed relation between pest intensity and yield loss irrespective of crop growth conditions. Since these conditions may vary considerably, results may be variable.

Statistical approaches, as described by Daamen (1987) may be dynamic or static i.e. the concept of time may or may not occur in the calculations. In statistical approaches observations are done only at the systems level - the growing crop and the pest populations. Usually, crop growth and yield in field experimental plots with pests present are compared with plots in which pests are controlled. By repeating experiments in different years and at various places, a relation between yield depression and pest density can be determined.

Single point, multiple point and the area under the disease/pest progress curve to determine EIL

Single point models and the area under the disease/pest progress curve are usually used to express pest intensity. In Table 1 some examples are given of equations which are used to translate pest intensity to yield loss in kg product or in money. Single point relations are most frequently used to relate yield loss to pest density. They are the easiest to derive but, since epidemics develop in time, they are normally very unreliable. In statistical terms, some improvement is often made with multiple point models.

Table 2. Some examples of equations based on single point, multiple point and area under the progress curve models, which relate percentage disease to yield loss (most from Smith *et al*., 1984).

Disease	Equation	Reference
1. Single point		
Septoria tritici wheat	$Y = -2.6943 + 0.6366\ X$ X = % disease on foliage at GS 59	Eyal (1972)
Puccinia graminis wheat	$Y = -25.53 + 27.17 \log X$ X = % disease at GS 75	Romig & Calpouzos (1970)
Pyricularia oryzae rice	$Y = 0.57\ X$ X = % diseased plants 30 days after heading	Latsibe & Koshimizu (1970)
Cereal aphids	$Y = 17.2 + 79.9$ X = density aphids tiller^{-1} at GS 75	Rabbinge & Mantel (1981)
2. Multiple point		
Rhynchosporium secalis spring barley	$Y = (0.66\ X_1 + 0.50\ X_2)\ 12$ X_1 & X_2 = % disease on flag leaf & leaf 2 at GS 75	James *et al*. (1968)
Puccinia recondita	$Y = 5.3788 + 5.526\ X2 - 0.3308\ X_5 + 0.5019\ X_7$ X_2 = % disease on culms at GS 44 $X_5 + X_7$ = % disease on flag leaf at GS 75 and 85	Burleigh *et al*. (1972)
Phytophthora infestans potato (early infection)	$Y = 1.867\ X_1 + 0.446\ X_2 + 1.144\ X_3 + 0.628\ X_4 + 0.193\ X_5 + 0.180\ X_6\ (+0.0X_7) + 0.343\ X_8 + 0.829X_9$ where $X_1 \ldots X_9$ = % defoliation increments over 9 weeks	James *et al*. (1972)
3. Area under disease curve		
Cercospora spp. cowpea	Area under curve of disease severity index (0-9) against time for at least 2 assessments from onset to harvest % loss = 0.43 (Area) + 14.95	Schneider *et al*. (1976)
Cereal aphids	Aphid days against yield loss	Rabbinge & Mantel (1981)
Fruit tree red spider mite	Mite days against yield loss	Rabbinge (1985)

In multiple point models, pest density is determined at various moments of the pest progress curve and the values, often weighted according to a statistically determined factor, are related to yield loss. The advantages of this method are that some concept of the dynamics of the pest is incorporated and that the relative weight of various pest intensities in the course of time may be considered.

Another dynamic approach is the concept of the area under the disease/pest progress curve. Here the density of the pest or severity of disease is integrated in time and related to yield loss. The "load" of the pest on the growing crop is nowadays emphasised in studies on crop loss assessment and in supervised control schemes, such as EPIPRE. However, the implicit assumption that there are no "critical periods" may be invalid. In many cases, early or late attacks of the pest will have quite different effects on crop growth and yield. Shaw and Royle (1987b) take this into account by proposing essentially an improvement of "the area under the disease progress curve" method. They relate the disease present at every instant during the growth of the crop to the final yield, through a rate of yield loss function. By integration of this rate of yield loss an estimate of final yield loss is obtained. The data for such a function are obtained from yields and estimated disease progress curves in a set of field plots (Shaw & Royle, 1987a).

Dynamic programming to determine EILS

A method to determine the best timing of a control measure and the corresponding EIL is described by Onstad and Rabbinge (1985). They use dynamic programming, a method used in pest and disease management for the computation of EILs, and developed a deterministic dynamic programming algorithm for tactical decision-making in cereal aphid control. This algorithm was used to identify two discrete values of the state variable APHIDS, that describe the number of aphids per tiller, between which the control policy changed from no treatment to aphicide treatment. This is then defined as the EIL. By this procedure the estimated curves for dynamic EILs fall between several sets of two points. In Fig. 1 the symbols represent these calculated points, the curves are interpolations. By using narrower intervals between the discrete values of the state variables the range of these points could be reduced. The change in EIL between crop development stages is striking, even more so when yield levels are also considered. The above study was done for a yield level of 8 t/ha^{-1} of wheat, but would change with lower or higher yield levels.

Dynamic explanatory approaches

The methods described above may be used to estimate yield loss expectation. However, they are based on a description of the field situation. Although much information is analysed in detail, these methods do not give insight into the causes of damage. Extrapolation to unknown field conditions is therefore dangerous, as the consequences of the interaction between pest and crop may vary considerably and may result in a different yield loss - pest density relation. For example, weather conditions may not only affect the epidemiological development of a disease but also the host-pathogen relation (Zadoks & Schein, 1979). Besides time and place of the pest, the crop growing conditions may affect considerably the extent of yield reduction. At high leaf nitrogen levels

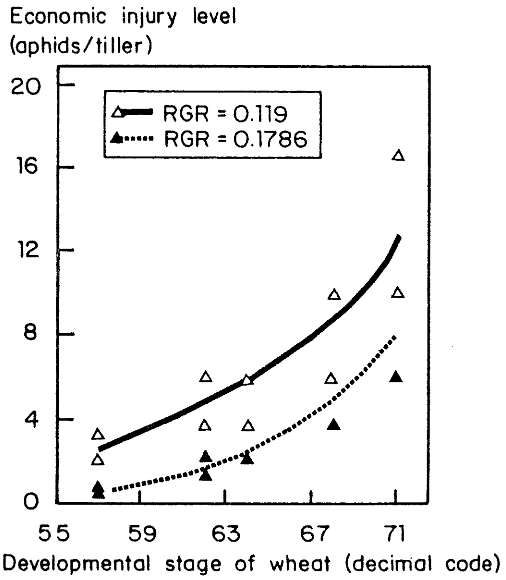

Fig. 1 Economic injury level of cereal aphids on wheat as a function of developmental stage. EILs are also influenced by assumed value of relative growth rate of aphid population. Dots represent ranges in which EILs exist. Results are based on average conditions for the Netherlands (Onstad & Rabbinge, 1985).

development of many diseases is promoted, since the latent period is longer and the infectious period shorter with low nitrogen. Another effect concerns the consequences of nitrogen status on the growth and yield reduction per unit of pest. This may vary considerably for different pests, diseases or weeds. With an increase in yield the competitive ability of a crop increases, so that the influence of growth reduction is less important. Weed control is then of less importance especially in the linear phase of crop growth. Pests and diseases are usually more important at higher yield levels. A good crop condition, needed for higher yields, and favourable micro-meteorological conditions in a dense crop may promote development of many diseases and affect the yield loss - pest density relation. The increase of winter wheat yields in Western Europe in the 1970s is for a large part due to better pest and disease control in crops with a high yield potential (Rabbinge, 1986). The increased importance of pests and diseases at higher yield levels is exemplified for cereal aphids. In wheat field experiments (Rabbinge et al., 1983) at a yield of 5000 kg ha^{-1} and a maximum density of 15 aphids at late watery ripe growth stage, these organisms caused a yield loss in kernels of 250 kg ha^{-1}, whereas a similar aphid load at a yield level of 8000 kg caused a yield reduction of 900 kg ha^{-1}. This is discussed further by Rabbinge (1987).

Apparently, cereal aphids cause progressive damage at increasing yield levels. Other diseases (e.g. mildew) cause proportional damage per unit of disease (Rabbinge, 1986). The reasons for this difference lies with the nature and manner of growth and yield reduction. In the examples above, with pests and diseases on winter wheat, such a dynamic explanatory analysis has led to better insight into the causes of damage and its consequences for yield reduction under various conditions. The shift in importance of the dependence on crop growing conditions of various diseases is determined by crop physiological processes. When abundant nutrient conditions and other favourable circumstances prevail, CO_2 assimilation is very high; assimilate consumption by an aphid may increase growth rate as the plant sink is limited. Under poor conditions, however, source limitation may occur (Rabbinge & Koster, 1984). This and other physiological phenomena may affect growth reduction or, in very rare cases, promote growth rate.

The presence of such effects limits the use of fixed EILs; they are inappropriate, since yield expectation differs considerably in different circumstances. Determination of flexible EILs would require endless field experiments and it is for this reason that other methods are more appropriate. Methods based on simulation studies combined with field experiments seem to answer this need for further refinement of EILs in pest and disease management.

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