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12.1 Introduction

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Awareness of the detrimental effects of diseases and pests on crops has led agriculturists to attempt to monitor and control the densities of the harmful organisms. Such practices are very old. The early Egyptians, for example, had developed monitoring systems of locusts, to warn growers so that they could take control measures. These measures were mechanical killing of locusts and noise production by huge numbers of people to prevent landing of locust swarms. In one of his speeches, King Solomon paid attention to the development and improvement of locust control But methods to foresee when swarms could be expected were not developed and therefore preventive measures were impossible in those times. Nowadays our knowledge of control methods and locust swarming has increased considerably. Reliable spraying methods of today using pesticides have replaced the unreliable praying methods of historical times. Nevertheless, the forecasting and control methods of Pre-Christian times are still widely used for many unknown or little studied pests and diseases. In this session we will discuss some of the warning systems that are applied or are in development in modern agriculture.

I will try to give a classification of such warning systems, and I will try to formulate criteria that should be met if these warning systems are to operate as useful pest or disease management tools.

Pest and Disease Management

In the last decade, pest and disease management have become accepted terms for applied entomologists and plant pathologists. This is due to a revolution in thinking. The rather single minded concept of eradication or total exclusion of a plant pest or disease has changed and made place for the concepts of supervised pest control and pest and disease management. One reason for this revolution in thinking on pest and disease control are the serious reactions of ecosystems in response to overabundant use of pesticides. Among these reactions were the development of resistant strains, the resurgence of treated populations in higher numbers, outbreaks of formerly secondary pests, population reductions of beneficial insects, and subsequent effects on other animals including humans. Another reason is the considerable increase of our knowledge on the biology of harmful organisms and their population dynamics. Our increased capability to synthesize this knowledge in large information systems opens the way for its use in integrated control systems. Pest and disease management depends on knowledge of crop economics, of economic thresholds, of population dynamics, and on the use of control techniques commensurate to the effect desired. This way of control holds the promise of improved stability of production, standardization of integrated control procedures, and, most important, rapidity and flexibility of response to outbreaks of pests and diseases, while minimizing the repercussive effects of the ecosystem.

Only few reliable systems of either supervised or integrated control are applied today. This is probably due to the high level of biological knowledge needed for such systems and the sophisticated technology environment which is often indispensable. As a result, a sociological gap exists between the research workers that develop sophisticated pest and disease control systems in the laboratory and the experimental plot on one side and the farmers who must apply these systems under far from ideal working conditions on the other. Too often this gap is overlooked by research workers in their laboratories. Furthermore the farm advisory role adopted by extension services and sales persons of the chemical industry often is to continue to promote what they understand best, namely the old doctrine that a crop should be clean and spotless. Extension scientists may show the way to bridge the gap. Supervised control may be applied for one single pest or disease, but fairly often it encompasses all prevailing pests and diseases of a specific crop.

Control of different diseases and pests requires different control procedures of population growth of harmful organisms. Zadoks and Schein [1979] expressed the possible control strategies for plant diseases in a single diagram. It shows how a disease may be delayed or set back by (a) sanitation, (b) change of planting time, (c) partial resistance, (d) treatment with eradicant fungicide, (e) treatment with protective fungicide, or (f) residual adult plant resistance, or repeated fungicide treatment. The same diagram holds for insect pests when biological control measures with natural enemies are not considered. In cases of biological control complete eradication of the prey population is usually not the aim. Parasite or predator and host or prey are rarely found in high densities when biological control is stable, as seen with many pest organisms such as spider mites in fruit orchards or cereal leaf beetles in wheat.

Injury or Damage Levels

In the preceding sessions of this symposium, much attention was given to the effect of a pest or disease on its host plant. The concept of economic injury levels, or damage thresholds, was defined as the lowest population density that causes economic damage and justifies the cost of artificial control measures. When the damage threshold is known and the disease or pest is present, the farmer must know when and how to act; thus we must also define an action threshold which occurs earlier than the damage threshold.

Appropriate control measures should be applied at such a time that the increase of the pest or disease is delayed and the damage threshold is not reached. Knowledge of the effect of spraying has to be combined with detailed knowledge of the development rate of the harmful organism. The action threshold presumes such knowledge and also presumes that sufficient time exists for control measures to be applied and to take effect before the population reaches the economic injury level.

The method of warning farmers for action is the subject of this session and will lead us to different systems depending on the crop, its pests or diseases. In ornamental crops, for example, the economic injury level is so low that the former criteria of clean and spotless crops are still in use, thus making warning systems impossible. Frequent and close monitoring is needed. The same holds for many short season vegetable crops.

Classification of Warning Systems

A classification of warning systems is arbitrary. The one presented here should be considered as a preliminary attempt to cover many, but not all, warning systems.

The simplest warning system is to make direct observations of the harmful organism at regular times. Although that method may give a good impression of how the pest or disease develops, its costs are high. Too often a farmer is asked to inspect his field, frequently without his understanding of what he is observing. Systems like that are in use in many crops but will probably evolve into one of the more advanced approaches discussed below.

A system in which some field observations are replaced by suction, pheromone or other trapping methods is avilable in some crops and for some specific insects. The reliability of those methods is low but sufficient to warn the farmers to start inspection of their fields and in some cases even to recommend spraying. Methods using suction traps or pheromone traps have to be complemented with field observations, since these traps measure only activity, which is sometimes but not always correlated with actual density of the harmful organism. An extension of the suction trap or pheromone trap system is the phenological recording system. The suction trap catches and the pheromone trap catches are then combined with calculations of when and at what rate the pest population will develop so that warnings may be given in advance. In those cases the development rate of the harmful organism is assumed in those cases to be linearly related to the temperature above a development threshold so that the actual development stage of the pest can be expressed by a temperature sum. But in many of those cases, it has not been established whether insect development really is a linear and instantaneous reaction to temperature. However the wide application of physiological time and temperature sums in warning and forecasting systems indicates that these systems can be useful. Although the biological basis for these systems is narrow, they still form the most developed warning system for classical pest control. The system can be run without use of computers or other sophisticated technological equipment and needs only a low input of biological knowledge. Examples of such methods which are discussed in this session, include the cereal aphid warning system. In that case, suction trap catches are used to give an indication when and where aphids may appear so that directed sampling in the field can start. The improvement and extension of that system by making use of computer-based models is a new development that seems promising. Other examples of systems in which early observations of the harmful organisms are combined with field sampling were given in the symposium for integrated control in fruit orchards. Another modern system of early observations of pests and diseases involves the use of satellite observations. Examples of use of satellites are found in locust control, and the observations of cloud patterns to predict outbreaks of black stemrust on wheat in India, well documented by Dr. Nagarajan. The high expectations of many plant pathologists in the 1960s and early 1970s for early detection of diseases and pests by remote sensing methods is now somewhat reduced by the disappointingly low resolution of the instruments, the considerable technical difficulties, and the high costs. The next decade may show better prospects for these methods but at present their value seems to be very limited. More laborious and technically less sophisticated methods seem to have a better chance for success.

Another system requiring much technological knowledge and equipment is the system of negative prognosis. Action and warning thresholds should be known in that case so that it is possible to determine whether it is necessary to take action or not. Two examples of this system have been developed and widely applied during the last decade. Both systems operate for potato late blight, one in the USA called BLITECAST and one in the Federal Republic of Germany called PHYTPROG. The last system will be presented in this session. Systems like these are based on records of daily rainfall, maximum and minimum temperatures. In BLITECAST the initial appearance of blight is forecast 7 to 14 days after the first occurrence of 10 consecutive blight-favorable days during which the daily 5-day average temperature is below 25.5 °C and the total rainfall for the last 10-day period is $\geq$ 30 mm. In BLITECAST forecasts of the first occurrance and subsequent spread may be based also on relative humidity and temperature and is used to establish severity values. Those are arbitrarily assigned to specific relationships between duration of RH period $\geq$ 90% and the average temperature during those periods. BLITECAST and PHYTPROG are computer based programs that combine the different estimation methods. A farmer who participates in the system has a thermohygrograph which records data for his field specifically. By telephone communication with the central system he can be informed if a treatment for his field is necessary, based on the data collected for his field and the presence of an initial infestation in the region. BLITECAST gives recommendations to skip spraying and to continue measurements and provides warning or advice for different spray schedules. Similar systems developed for other pests and diseases are not based on a field by field operation but on a general warning for a whole area. Warnings are then broadcasted or advertised in agricultural newspapers. The advice is in those cases not tailored to the farmer's field but as a ready-made package, which may not be valid for the specific conditions.

Published and broadcasted warnings are in most cases based on a combination of phenological observations, heat sums, and field surveys. The value of such systems for the actual pest and disease management of the individual grower, however, is limited. The advice should provide an impetus to the farmer to go out into the field and make his own observations. The introduction of huge information systems makes the development of warning and pest and disease control systems on a field by field basis possible. These computer-based systems are used especially in integrated control systems and their characteristics will be treated in much detail in the first contribution to this session by Dr. Welch. A careful analysis of user's behavior should precede the implementation of these systems. Demands on technological equipment, the biological information, the educational level of the users, and weather information are quite high so that only few examples of successfully working Integrated Control Systems using such sophisticated methods are available. It is questionable whether the implementation and improvement of these systems are possible in all environments and crop systems. In some cases the introduction of computer-oriented pest warning systems may even be undesirable since it will interfere with proper IPM systems. For example, the present system of integrated control in Dutch fruit orchards could be disturbed and cause a lower control if a computer based approach is introduced.

Criteria for a Good Warning System

The foregoing offered requirements for a good working pest and disease warning system for use in plant protection which are now summarized. The first criterion is simplicity: the system should be simple such that the message to or activity of the farmer is a simple one. Counting schemes or spraying criteria should not be too complicated. As an illustration I may quote our own work for pests and diseases control in wheat, EPIPRE. In this project the criterion for spraying against cereal aphids formerly was set at 15 aphids per ear. The counting required to determine this density was so laborious yet often so inaccurate that another, easier and more reliable, method was urgently needed. To meet the requirement of simplicity we now only count the number of infested ears since, when aphid numbers are below 5 per tiller, there is a linear relationship between the probit value of the proportions of ears infested and the natural logarithm of the average number of aphids per tiller. When higher densities are present the proportion of tillers with over 10 aphids per ear is determined as there appears to be a linear relation between the median of the aphid density per tiller and the average aphid density; thus average density is again determined by a reliable and simple sampling technique. The next criterion is that the warning system has a sound biological basis. A warning system based purely on empirical data may prove reliable for some consecutive years but may be unreliable when conditions change. For this reason, biological knowledge on, for example, the rates of development, reproduction and mortality of the harmful organism should be combined with knowledge on its relation with its host plant and its natural enemies. It seems self-evident that a warning system should also be reliable, but often the absence of well defined verification experiments to test the value of the warnings and advice makes independent judgement impossible. Thus a warning system should be tested thoroughly in experiments in different regions and under various conditions before it is introduced into practice. Participation in a warning system should not require exhaustive amounts of observation time from the user, since then the cost/benefit ratio of the warning system is too great. For this reason, simple low-labor monitoring techniques and short decision processes, simple decision rules and fast communication between user and extension service or other advisers should be guaranteed.

A warning and monitoring system should not be considered as a separate crop management activity but should be compatible with other management activities since a combination of activities and observations limits costs and makes its use more attractive. For this reason, warning systems should be designed such that combination of activities is possible. Since biological systems are subject to change and our knowledge of them is still growing, the criteria for spraying, the observation techniques, and the control measures may change with increasing insight of the crop ecosystem including the prevailing pests and diseases. To guarantee a rapid adaptation of the warning system to this increased insight there should be close connections with research teams, or even better, these development experiments should be done by the supervisors of the warning system. The final decision to introduce the crop management system should be based on a cost/benefit analysis with appropriate environmental consideration. Therefore, the costs of running the warning system should be as low as possible; this is promoted when a complete crop protection and management system is offered. The basis of the decision to introduce sophisticated warning systems will be different for each situation.

In this session we will see how the decision, to develop complex and very expensive warning systems, are sometimes warranted to prevent complete disasters as in the cases of locusts in Africa and of potato blight in the western world. In the other contributions, simpler but still expensive warning systems will be presented. A definite cost/benefit ratio is absent in those cases but rough estimates indicate that their value is unquestionable.

This session will treat only a few examples of pest and disease warning systems. These examples, however, provide an introduction to an approach which may have a bright future.