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IMPLEMENTATION OF INTEGRATED CROP PROTECTION SYSTEMS

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Introduction

The ultimate aim of research in crop protection is the introduction and application of its results into practice. To reach that goal close ties with end-users, farmers and extension need to be maintained in on-going research. The means of communication haVE changed during the last decade as new methods have become available. Summary models and decision rules formulated into software packages have been developed and are now being used. These methods of implementation have been considered in the last five workshop meetings of this IOBC Working Group and have resulted in some general ideas on the role of the various participants in this process of development and improvement of integrated crop protection. In this scenario integrated crop protection is viewed as part of farm management that leads to sustainable, stable and rational production of agricultural products with little use of energy or biocides per unit of product. These ideas have been substantiated in a list of steps in implementation that have been generally accepted in the Working Group. These concern activities on the levels of management of pathosystems and cropping systems. Farming systems and agroecosystems, the next higher integration levels, are not usually considered by the Working Group, although the ultimate aims of integrated crop production should be fulfilled by activities on these levels.

Steps in developing and implementing integrated crop protection systems

Monitoring and Sampling. The basis of each supervised or integrated pest or disease control system consists of observations on the number or density of the pest or disease organisms. In some cases this can be done with indirect techniques which consider presence or absence but not numbers. However, it is often impossible to relate the actual numbers per field to counts of individuals in a suction trap or by another indirect technique. Therefore, observations in the field are needed to determine crop development and the infection level of disease or infestation level of pests. Such observations should be simple for laymen, reliable for use in initialising models, solid, i.e. take into account the specific biological requirements, and not be time-consuming. In EPIPRE, for example, all observations are standardized in order to determine infection or infestation levels. These are then translated into severities or densities using statistically sound calibration techniques (Daamen, 1986; Rabbinge et al., 1981; Ward et al., 1985). In EPIPRE all diseases and pests are observed in the same way, by inspecting particular leaf layers for presence or absence, and it is indicated when each disease or pest should be observed. Farmers or scouts should not spend too much time monitoring: in EPIPRE no more than 1 hour ha^{-1} $year^{-1}$ is recommended as a longer time would encourage too much detail and result in sampling bias. Moreover, 1 hour ha^{-1} $year^{-1}$ means about 12% of all the labour required to farm one ha of wheat from sowing until harvest in present capital-intensive wheat production in Western Europe. In the U.S.A. and Australia, the labour requirement per ha of wheat is even less than 6 hours ha^{-1} $year^{-1}$, therefore monitoring time should be less than 1 hour to prevent disproportionalities in time use. This is quite possible, as yield reducing factors are normally less important in situations where water and nutrient shortage limit the attainable yield, which is normally the case at yield levels between 2000 and 5000 kg of wheat ha^{-1}.

In other crops, e.g. apple, more monitoring time seems justified because of larger labour requirements for production. Research and extension should develop monitoring methods which are tailored to the specific needs of the crop and fulfil all the above criteria.

Forecasting of pest and disease severities. To decide whether control measures, biological or chemical, should be applied it is necessary to have forecasts of expected pest or disease severities and estimates of the corresponding yield reductions under the prevailing growing conditions. Such forecasts can be made with summary type models based on detailed insight of epidemiology and population dynamics or with regression type models. In the latter case extrapolation to new situations is dangerous as the system may then behave differently. Extrapolation with comprehensive explanatory models is not such a problem since the basic processes which govern the systems behaviour do not change.

Crop loss assessment. Forecasts of pest and disease severities are used to determine the expected yield loss which may depend on crop conditions, yield expectation, timing of the pathogen in the growing season and environmental conditions, as demonstrated by Rabbinge (1987) for powdery mildew and cereal aphids in winter wheat. Recommendations for control measures should be based on cost/benefit analysis. Costs of control measures should not exceed the predicted yield loss. Advice should be field-specific and take into account the history and prospects of the crop, including presence or absence of growth and yield-limiting and reducing factors. Such decision-making requires much field-specific information and information processing. Computers, even nowadays microcomputers, may be used to implement this process. This is needed even more when, for example, risk is introduced. Some farmers are risk-seeking, the majority risk-averse. However, there may not always be a logical justification for this (Zadoks, 1987). There is a clear need to make explicit the scale of risk and also the costs needed for various control measures. To do this simulation models incorporating such effects may help to quantify the consequences of various tactics. These simulation models help to make an explicit choice for risk-seeking or risk-averse behaviour; they replace "gut feelings" by "calculated risks".

Farmers' attitudes towards pest or disease control are not implicit in recommendations, and decision-making requires explicit choices. This is very important as it may change the tendency to incorporate farmers attitudes in integrated pest and disease control systems.

Implementation. Most supervised or integrated pest and disease management systems which are computerised are nowadays centralised. However, there is an increasing tendency towards decentralisation. This is made possible by the recent rapid development of appropriate hardware. In most cases appropriate software packages are not available. Moreover, the advantages of stand-alone, do-it-yourself systems may be offset by the disadvantages of delays in updating and upgrading decentralised systems.

Sudden resistance of a pest towards a pesticide will require immediate modifications in the recommendations in centralised systems; but with decentralised systems modifications can wait until the end of the season, when all updating and upgrading of software packages is done. Therefore, decentralisation may have some disadvantages which may be overcome by a combination of centralised software development with decentralised operation. Computer networking and new communication systems may be helpful. For the development of software, research, extension and private industry need to interact closely. Vital for quality in the software packages sold to end-users is for the incorporated information to be objective and scientifically sound. The independent role of research institutes and government-supported extension services is therefore justified.

Role of research and extension. A supervised control system is not an end in itself. It is a part of the cropping system which is constantly changing in response to environmental changes. It is therefore necessary to adapt and improve integrated control systems frequently. Choice of crop varieties changes, resistance against disease may be broken, resistance against certain pesticides may develop and agronomic measures, such as sowing or crop rotation, may be changed. This is why a continuous updating of control systems is needed. Research and extension are responsible for this updating as part of other agronomic activities. Another role concerns upgrading of the system. When a supervised or integrated control system is compiled, much of the information and many recommendations are based on empirical data and the experience (so called "green fingers") of the scientist or extension officer. With increase of knowledge and insight this type of experience can be replaced by quantitative facts which are transferable and understandable, i.e. "green fingers" are steadily replaced by "green brains". However, the complexity of farm management will always need the experience and care of the farmer. Computer simulation and knowledge may support his decision-making and help to improve it, but they cannot replace it.

Results of implementation. The use of models as integrative tools has been stressed in other contributions to this Bulletin. It is this role of models which has made them so powerful for research. Models as vehicles for decision-making are nowadays promoted more and more. However, it is not yet possible to demonstrate clear successes. In some crops, e.g. cotton, apple, wheat and grape, computer-sustained supervised control systems which comprise models at various levels of sophistication have been introduced. Their immediate use may be limited but will grow when the objective of crop protection is broadened to crop management or even wider, farm management systems. The impact of first generation systems like EPIPRE is already impressive (Zadoks, 1987). It is not the number of users but their general attitude towards crop protection in wheat that is of importance. Their environmental consciousness, their general attitude towards chemical crop protection, especially reluctance in spraying, their cost consciousness and acceptance of aesthetic "damage" in the Netherlands can be credited to EPIPRE. Effects of these attitudes are shown in a comparison between various systems of pest and disease control in the Netherlands and England (Table 1). This comparison may seem unfair to the extension service of England and Wales, but nevertheless shows how effective chemical companies have organised their extension messages in Britain. The difference between systems of wheat growing in the Netherlands and the U.K., due to farm size and other

Table 1. Crop protection measures in winter wheat. Data from England are based on the Boxworth experiment and extension data; data from the Netherlands are based on EPIPRE and extension data.

	England			Netherlands		
	Intensive	Integrated	Reduced	Intensive	Integrated	Reduced
Pesticides						
Slugs	+	0	0	-	-	-
Aphids (virus)	+	+	0	-	-	-
Frit fly	+	0	0	-	-	-
Grain aphid	+	+	+	+	0	0
Rose grain aphid	+	+	+	+	-	-
Fungicides						
Seed treatment	+	+	+	+	+	+
GS 31	+	0	0	+	0	-
GS 39	+	+	+	-	-	-
GS 59	+	0	0	+	0	0
GS 71	+	0	0	-	-	-
Herbicides						
Pre-sowing	+	-	0	-	-	-
Pre-emergence	+	-	0	-	-	-
Post-emergence	+	+	+	-	-	-
Spring	+	+	+	+	+	+
Pre-harvest	+	-	+	+	-	-
Growth regulators						
GS 31	+	+	+	+	0	0
GS 41	+	-	-	+	-	-

\+ spraying at predetermined development stages or times, or when symptoms are visible
0 optional; only when predetermined pest/pathogen density is reached
\- no spraying against these organisms

Intensive: Intensive crop protection
Integrated: Reduced use of control measures, using monitoring and forecasting methods and fixed action thresholds
Reduced - Reduced crop protection, using monitoring and forecasting methods, flexible well-defined action thresholds, and calculated risks

GS = Crop Growth Stage (decimal scale of Zadoks et al. (1974).

factors, also explains some of the differences, but without doubt the use of pesticides per kg of wheat is far less in the Netherlands than in England or Schleswig Holstein (W. Germany). The input of labour needed for monitoring is clearly higher in the Netherlands, but this offsets the reduced cost of chemical compounds. Apparently chemical energy can be partly replaced by brains energy!

More research and proper extension activities may help in this way to optimise, rather than maximise, agricultural production. High stable yields require high inputs but a very high labour efficiency. The efficiency of other inputs is also promoted when enough knowledge is brought to the farmer's field. This will continue to require co-operative effort among research, extension, private industries and farmers.

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