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UNCERTAINTY AND TACTICAL DECISION SUPPORT IN WINTER WHEAT PEST MANAGEMENT

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ABSTRACT. Timing of chemical control of pests and diseases is a decision problem which consists of objectives, strategies, a model of the system, and decision criteria. 'Return on expenditure' and 'insurance' are generally applicable, potentially conflicting objectives of pest control. Uncertainty about the costs of different strategies of chemical control of cereal aphids (especially *Sitobion avenae*) and brown rust (*Puccinia recondita*) in winter wheat is calculated with a deterministic model. Sources of uncertainty, which comprise estimates of initial state and parameters, future weather, and white noise, are modelled as random inputs.

A widely used decision criterion in crop protection is the damage threshold, defined as the level of pest attack where projected costs of immediate control just equal projected costs of no control. No chemical control is the recommended action when the level of pest attack is below the damage threshold. It is shown that ignoring uncertainty leads to wrong recommendations.

It is argued that a consultative decision support approach which emphasizes the consequences of strategies in terms of objectives, is more appropriate than a prescriptive approach which concentrates on applying decision criteria to find the 'optimal' strategy. A consultative framework is proposed in which strategies are analyzed in terms of 'return on expenditure' and 'insurance'.

1. Introduction

Supervised control is the dominant paradigm in tactical decision support in crop protection (Zadoks, 1985). The concept is based on maximization of returns on expenditure for chemical control, but applies also to other methods of pest management where proper timing

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is required. The optimal time of pesticide application is considered to be equivalent to the level of pest attack at which the projected costs of chemical control just equal the projected costs of no control. This level is called the damage threshold. Mathematical models are used to calculate costs associated with decision alternatives. The current state of the system, characterized e.g. by pest density or crop development stage, is input for the models and is established by monitoring. The recommended decision is presented to the farmer in a decision support system.

Typically in current decision support systems, recommendations are prescriptive, contain no information on the uncertainty associated with decision alternatives, and are adjusted to be 'on the safe side', i.e. biased to chemical control. Since farmers appear to use information from various sources before arriving at a decision (Tait, 1987), unbiased information on the uncertainty of decision alternatives appears more useful than recommendations in which a farmer's presumed risk-attitude is implicitly accounted for (Rossing *et al.*, 1993a). Therefore, a probabilistic as well as consultative approach to decision support is called for, rather than a deterministic, prescriptive approach.

In this paper the importance of uncertainty for supervised control of aphids and brown rust in winter wheat in the Netherlands is investigated. Two questions are addressed. Firstly, to what extent do damage thresholds change when uncertainty is taken into account. Secondly, how can information on uncertainty about costs associated with decision alternatives be made operational for consultative tactical decision support in crop protection.

2. Research approach

2.1. DECISION MODEL

A deterministic simulation model is used to predict costs of spray strategies at given initial temperature sum and initial levels of pest attack in a winter wheat field in the Netherlands. A spray strategy consists of a series of decisions on chemical control of aphids, brown rust or both, with fixed, one week time intervals. Costs of a strategy comprise the monetary equivalent of yield loss due to pest attack plus the costs of eventual chemical control.

The decision model consists of mathematical relations describing crop development, population dynamics and damage per unit of pest density. Relations are based on data collected during multi-year, multi-location experiments. The decision model represents an upgraded version of parts of the EPIPRE advisory system which has been operational in the Netherlands for over a decade (Daamen, 1991).

Crop development is calculated as a function of temperature sum above a developmental threshold of 6°C, accumulated from crop development stage pseudo-stem elongation (DC 30, Zadoks *et al.*, 1974).

Population dynamics is calculated using observed incidences of aphids and brown rust incidences, i.e. observed percentage of sample units containing the respective pest. Incidence is transformed into density, which is assumed to increase exponentially with time. The relative growth rate of the aphid population decreases with advancing crop development stage. For brown rust the relative growth rate is constant. Aphicide application decreases population density by 85 % and arrests population increase during 12 days. In contrast, brown rust specific fungicides do not affect current population density and arrest population increase during 18 days.

Damage per pest-unit decreases linearly with advancing crop development stage for aphids and is constant throughout the season for brown rust. A maximum level of damage is assumed for both pests.

Uncertainty is represented as random inputs into the model. Four categories of uncertainty are distinguished (Figure 1). Uncertainty about initial incidences is modelled as binomial distributions with parameters depending on sample size and incidence estimates. Parameters in the mathematical relations were estimated using field data and regression. Estimated variance-covariance matrices provide measures of parameter uncertainty. Residual variance was ascribed to measurement effects and was disregarded for prediction. Some data sets were sufficiently detailed to allow estimation of the measurement variance. In those cases the surplus residual variance was ascribed to real, natural variability and was included in the model as mutually independent, identically distributed normal random inputs. This source of uncertainty will be called white noise. Uncertainty about future average daily temperature was described by 36 years of daily minimum and maximum temperature measured in Wageningen between 1954 and 1990.

Uncertainty about parameters and estimates of the initial state represents *controllable uncertainty*, since uncertainty may be decreased by collecting additional data. The categories future average daily temperature and white noise represent sources of *uncontrollable uncertainty*, as long as the structure of the model is unchanged.

Using stratified random sampling from the statistical input distributions in combination with Monte Carlo simulation estimates were obtained of the probability distribution of the major model output, costs of a spray strategy. Details are given in Rossing *et al.* (1993b).

2.2. TOOLS FOR DECISION SUPPORT: PROFITABILITY AND RISK

A decision problem can be decomposed into objectives, representing the goals of the decision maker, strategies, the means available for attaining the goals, a system model, representing the relation between strategies and their outcome, and decision criteria by which a decision maker chooses between alternative strategies. In a prescriptive approach to decision support identification of generally applicable objectives is followed by application of decision criteria to arrive at the 'best' strategy which is subsequently recommended to the decision maker. This approach ignores the subjective, variable nature of decision criteria in tactical crop protection as was pointed out by e.g. Tait (1987) who showed that attitudes to uncertainty vary

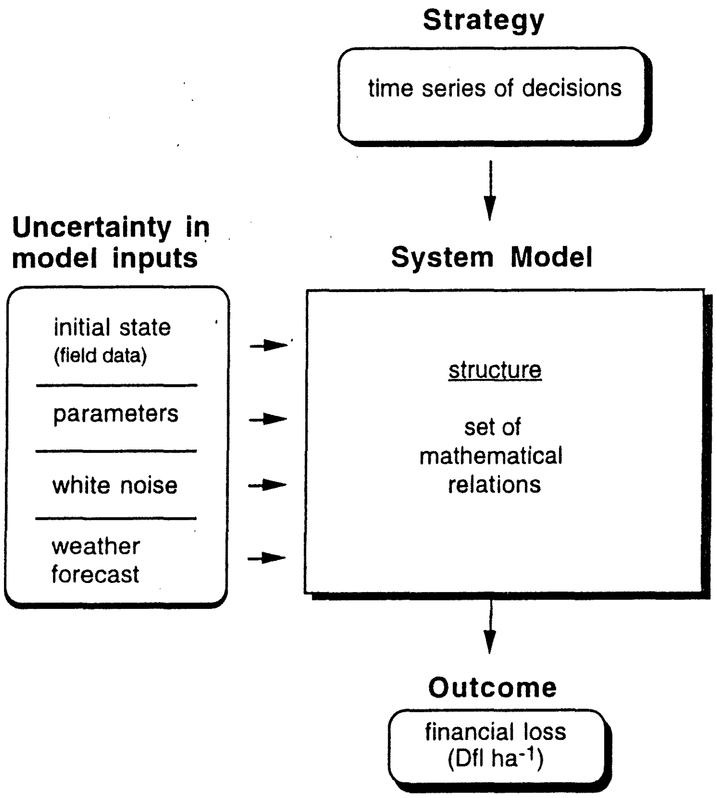

Figure 1. Outline of the decision model.

between farmers and, for individuals, vary between years. In contrast, a consultative decision support approach focuses on presentation to a decision maker of consequences of strategies in terms of generally applicable objectives. Application of subjective decision criteria, i.e. actual choice of the 'best' strategy, is explicitly left to the farmer.

Norton and Mumford (1983) postulated that two generally applicable aspects can be distinguished in objectives of pest control, 'return on expenditure' and 'insurance'. When emphasis is on 'return on expenditure' concern is primarily about positive returns to pesticide input. In this paper this aspect of pest control objectives is made operational by calculating the *profitability of strategy* A *compared to strategy* B, defined as the probability that strategy *A* results in lower costs than strategy *B*. When concern is predominantly about avoiding excessive costs, the 'insurance' aspect of pest control is stressed. Here, insurance-related aspects of pest control objectives are made operational by calculating the *risk of a strategy*, defined as the value of costs which is surpassed with an arbitrarily chosen probability of at most 10 %.

Each time a decision is to be made three (groups of) strategies can be pursued: no chemical control at any time, immediate chemical control, or postponing chemical control to some later point in time. Since 'profitability' involves comparison of two strategies, assessment of profitability of one strategy compared to another becomes cumbersome when the number of alternative strategies is large. We postulate that often the set of relevant strategies can be reduced to a manageable number by expert knowledge or, as in the present case, because of the nature of the system dynamics, *viz.* the dominant effect of exponential increase of pest density. For aphids and brown rust in winter wheat only no control at any time and immediate chemical control need be considered. Preliminary analysis showed that postponing chemical control causes profitability to decline and risk to increase, compared to immediate chemical control. Thus, whatever the subjective decision criteria, a rational decision maker (*sensu* Tait, 1987) who aims at maximizing profitability and minimizing risk, will never decide to carry out chemical control at a predetermined time in the future. The decision problem reduces to deciding whether at a given initial state of the system no chemical control results in an acceptable combination of profitability compared to immediate chemical control, and risk. If this is not the case, immediate chemical control is the preferred strategy. This decision process is repeated each time a decision is to be made, i.e. decisions are made with 'rolling planning horizon'.

3. Results and discussion

3.1. UNCERTAINTY ABOUT COSTS OF RELEVANT STRATEGIES

The decision model with random inputs was used to estimate probability distributions of costs of no chemical control and immediate chemical control for a single initial state of the system (Figure 2). Costs associated with no chemical control range from almost 0 Dfl ha^{-1} to 1200 Dfl ha^{-1}. For immediate chemical control costs range between almost 185 Dfl ha^{-1}, the fixed costs of a control operation, and about 500 Dfl ha^{-1}. The large difference in uncertainty about costs associated with these two strategies underlines the usefulness of information on the degree of uncertainty.

For both strategies expected costs are identical, approximately 200 Dfl ha^{-1}. Such initial state of the system where *expected* costs of no control equal *expected* costs of immediate control, will be called a stochastic damage threshold. A stochastic damage threshold represents a decision criterion to select the best among strategies. Since only expected costs of strategies are considered, this criterion implies that the decision maker is risk-neutral, i.e. neither prefers nor avoids high or low costs.

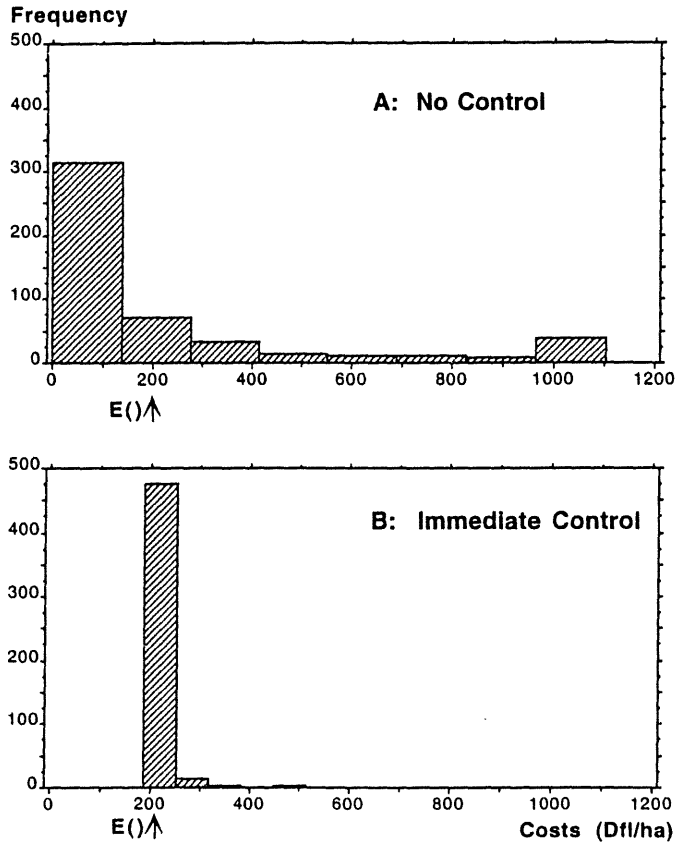

Figure 2. Frequency distributions of costs of no chemical control (A) and immediate chemical control of aphids and brown rust jointly (B) in 500 Monte Carlo runs. Initial state of the system: temperature sum 200 °days, equivalent with DC 58±4 (se), aphid incidence 5 % of 100 tillers, brown rust incidence 2 % of 160 leaves. The arrows indicates the expected value (E()) of costs.

3.2. UNCERTAINTY AND PRESCRIPTIVE DECISION SUPPORT: DAMAGE THRESHOLDS

The decision model with random inputs was used to calculate stochastic damage thresholds for cereal aphids and brown rust at a range of initial crop development stages. In comparison with deterministic damage thresholds which were calculated using mean values of model inputs, the stochastic damage thresholds were lower at all initial crop development stages (Figure 3). The discrepancy is caused by non-linearity, more specifically, by convexity of the decision model.

Compared to the current state of knowledge, perfect knowledge would result in spraying at higher pest incidences, resulting in on average less pesticide use. Thus, uncertainty has its price. Elsewhere, we analyzed the major causes of uncertainty and the way to most efficiently reduce it (Rossing *et al.*, 1993c).

Calculated stochastic damage thresholds were used as references to evaluate the assumptions in the damage thresholds used by the prescriptive decision support system EPIPRE concerning risk-attitude of farmers. With respect to cereal aphids EPIPRE appears to assume that risk-aversion increases with advancing crop development stage (Figure 3a). With respect to brown rust EPIPRE recommendations consider farmers to be largely risk-neutral (Figure 3b).

3.3. UNCERTAINTY AND CONSULTATIVE DECISION SUPPORT: PROFITABILITY AND RISK

Profitability of no chemical control compared to immediate chemical control and risk associated with each strategy are calculated for aphids (Figure 4) and brown rust (Figure 5). The profitability of immediate chemical control compared to no control increases as initial incidences of aphids or brown rust increase, and decreases with advancing crop development stage. In contrast, risk increases with increasing initial incidences, and decreases with advancing crop development stage for both strategies, irrespective of pest organism. Chemical control reduces risk. Clearly, return on investment and insurance are conflicting objectives in these pathosystems. To demand a high profitability of chemical control implies accepting large risk, while minimizing risk is equivalent to accepting a low return on expenditure for chemical control. The nomograms show the 'exchange rate' between these objectives, and provide a basis for decision making.

Stochastic damage thresholds are included in the nomograms as 'yardsticks', since they represent a well defined attitude to uncertainty. Fore both aphids and brown rust the stochastic damage thresholds are equivalent to a profitability of no chemical control compared to immediate control of approximately 70 %. In other words, although on average immediate chemical control is economically rational at initial pest incidences equal to or higher than the stochastic damage threshold, the majority of pesticide applications at the stochastic damage threshold are ineffective. The low probability of economically successful chemical control is caused by the occurrence of very high costs, although with low probability, when no chemical control is carried out (*see* Figure 2). To increase the effectivity of pesticide applications at the stochastic damage threshold, uncertainty about the costs associated with no chemical control should be reduced.

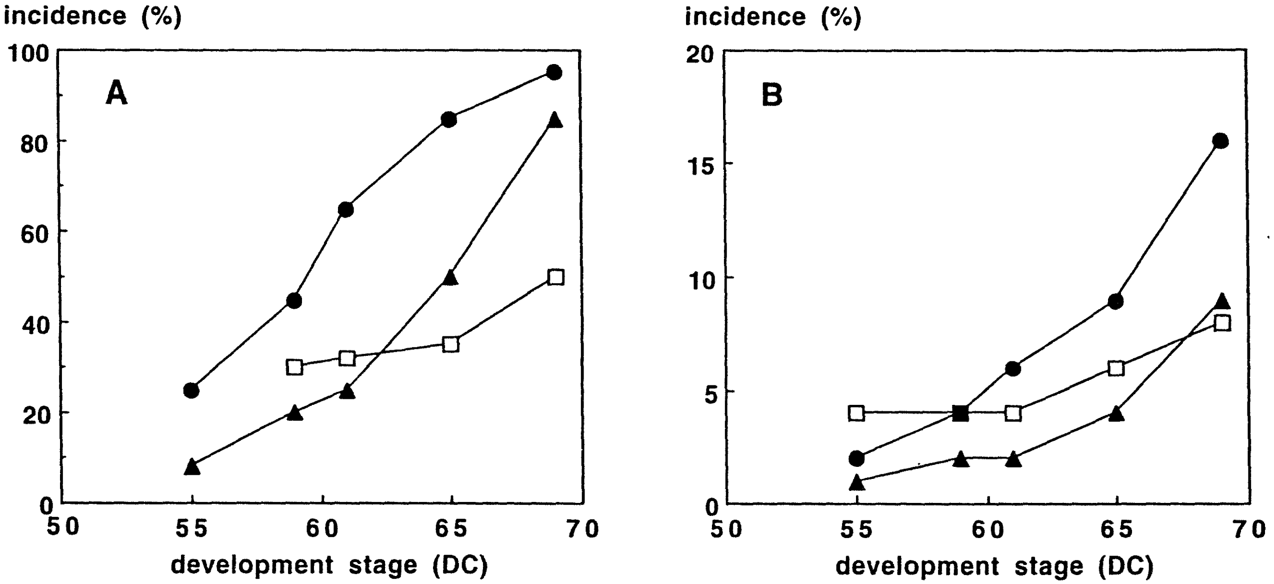

Figure 3. Damage thresholds for aphids (A) and brown rust (B) according to the deterministic version of the decision model (—●—), the stochastic version, based on 500 Monte Carlo runs (—▲—), and according to EPIPRE (—□—).

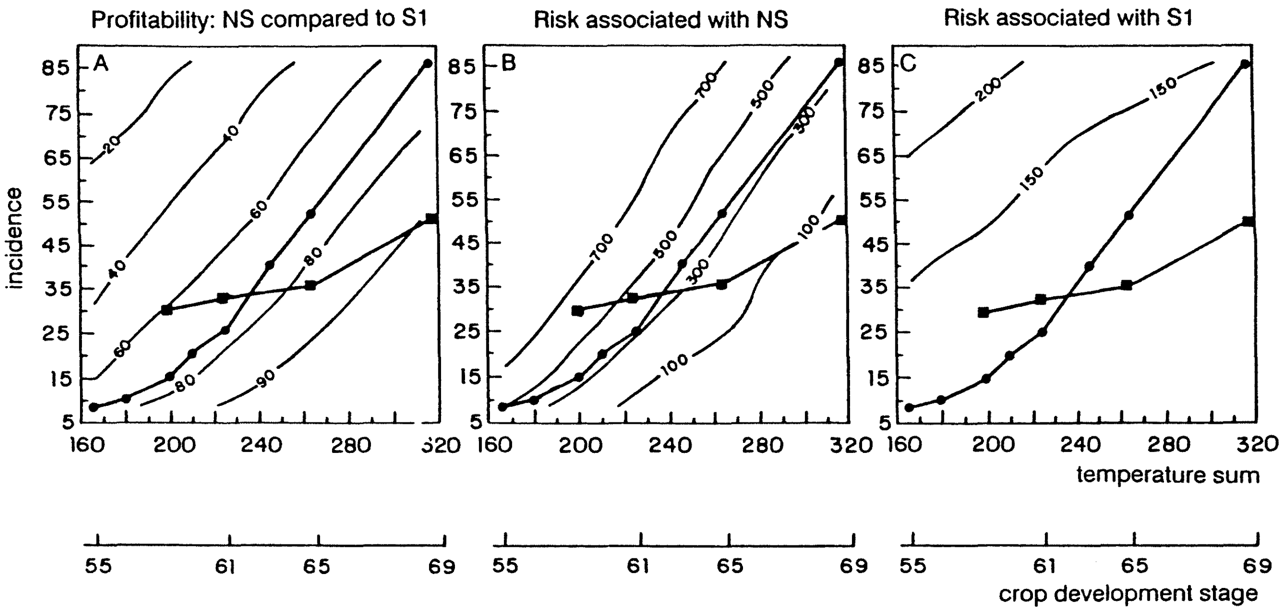

Figure 4. Contour plots of the *profitability* of no chemical control compared to immediate control of aphids (A), and the *risk* associated with no chemical control (B) and immediate chemical control (C), at different initial temperature sums (°day) or equivalent crop development stages (DC), and aphids incidences (%). Brown rust is absent. Profitability (%) and risk (Dfl ha^{-1}) are indicated within the contour lines. Also shown are the stochastic damage thresholds (—•—) and the EPIPRE damage thresholds (—▪—).

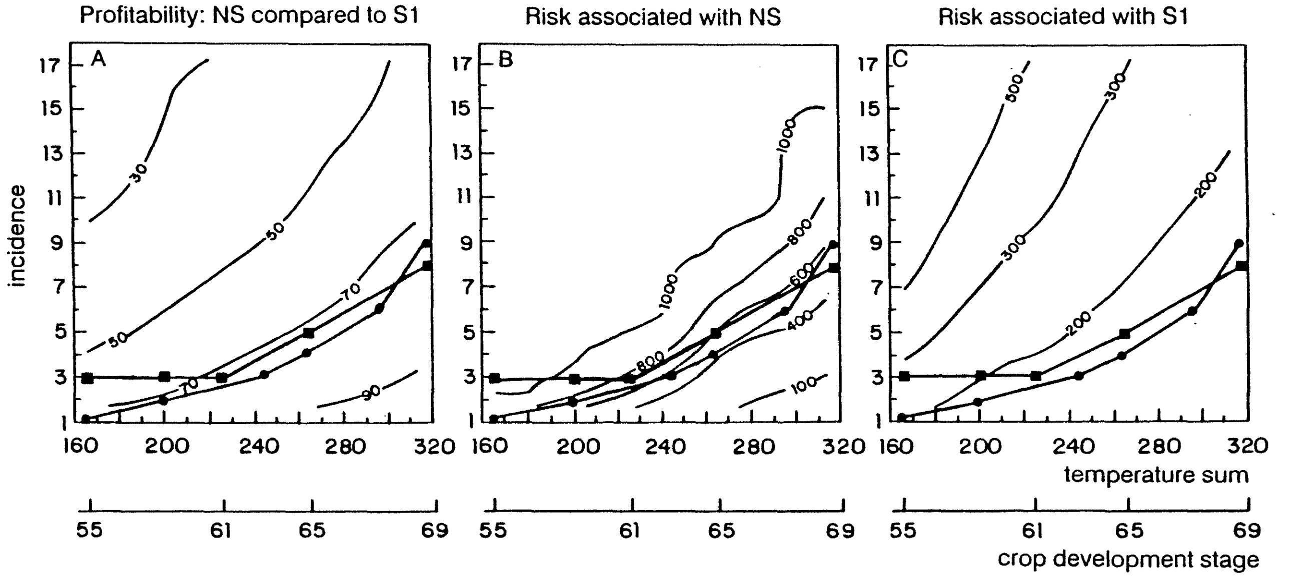

Figure 5. Contour plots of the *profitability* of no chemical control compared to immediate control of brown rust (A), and the *risk* associated with no chemical control (B) and immediate chemical control (C), at different initial temperature sums (°day) or equivalent crop development stages (DC), and aphids incidences (%). Aphids are absent. Profitability (%) and risk (Dfl ha^{-1}) are indicated within the contour lines. Also shown are the stochastic damage thresholds (—•—) and the EPIPRE damage thresholds (—▪—).

3.4. CONCLUSIONS

This paper focused on quantification of uncertainty about costs of pest control strategies and assessment of the consequences for tactical decision support. The results show that neglecting uncertainty will lead to wrong recommendations to farmers in prescriptive decision support systems. Further analysis shows that selection of the 'best' strategy as is done in prescriptive decision support systems is of limited value since generally applicable selection criteria do not exist. In contrast, specification of generally applicable objectives of pest control appears feasible and results in a consultative framework in which strategies are assessed in terms of profitability and risk. Further evaluation of the framework in relation to existing crop management systems is needed.

Reduction of uncertainty may be brought about by strategic crop husbandry decisions such as choice of cultivar or level of nitrogen fertilizer input, and by increasing knowledge of the system dynamics through research on those components which contribute most to uncertainty about costs.

4. References

Daamen, R.A. (1991b) 'Experiences with the cereal pest and disease management system EPIPRE in the Netherlands', Danish Journal of Plant and Soil Science 85(S2161), 77-87.

Norton, G.A. and Mumford, J.D. (1983) 'Decision making in pest control', Advances in Applied Biology 8, 87-119.

Rossing, W.A.H., Daamen, R.A. and Hendrix, E.M.T. (1993a) 'A framework to support decisions on chemical pest control, applied to aphids and brown rust in winter wheat', Crop Prot., in press.

Rossing, W.A.H., Daamen, R.A. and Jansen, M.J.W. (1993b) 'Uncertainty analysis applied to supervised control of aphids and brown rust in winter wheat. 1. Quantification of uncertainty in cost-benefit calculations', Agric. Systems, in press.

Rossing, W.A.H., Daamen, R.A. and Jansen, M.J.W. (1993c) 'Uncertainty analysis applied to supervised control of aphids and brown rust in winter wheat. 2. Relative importance of different components of uncertainty', Agric. Systems, in press.

Tait, E.J. (1987) 'Rationality in pesticide use and the role of forecasting', in K.J. Brent and R.K. Atkin (eds.), Rational pesticide use. Cambridge University Press, Cambridge, pp. 225-238.

Zadoks, J.C. (1985) 'On the conceptual basis of crop loss assessment: The threshold theory', Annual Review of Phytopathology 23, 455-473.

Zadoks, J.C., Chang, T.T. and Konzak, C.F. (1974) 'A decimal code for the growth stages of cereals', Eucarpia Bulletin 7, 42-52.