5.1 Decision making and data management

F.H. Rijsdijk, J.C. Zadoks and R. Rabbinge

5.1.1 Introduction

Decision making in crop protection management varies widely for different crops. This is because factors such as variety susceptibility, soil type and crop rotation influence the decisions that have to be made.

Often, the use of pesticides plays a major role. Depending on crop and disease, treatments are applied either preventively or immediately after the first observation of the pathogen in the field. Sometimes treatment is delayed until the disease intensity passes a threshold which justifies protective action. In any case, the attitude of the farmers, which vary from risk-avoiding to risk-accepting, is also important. One task of the crop protection scientist is to produce rules and algorithms to assist the farmer in his decision making, and so avoid the unnecessary use of pesticides.

Decision making in crop protection is just part of decision making in general management, and should be understood as such. Interrelation with other cultural measures, such as fertilization and crop husbandry practices, are essential in order to create optimal conditions for the use of decision systems in agricultural practice. In decision making, a distinction is made between strategic decisions and tactical decisions (Chapters 1 and 6). For both types, simulation could be useful.

Comprehensive simulation models on pest and disease epidemics as such are seldom an instrument for decision making in agriculture. Decision making requires algorithms and decision rules that are rarely derived directly from such simulation models, but they may be used to find such rules.

5.1.2 Tactical decision making in disease control

When preventive methods, such as varietal resistance, crop rotation or biological control are no longer sufficient, then chemical control is needed. In order to limit the use of pesticides, and to spray only when really necessary, computer supported disease management becomes desirable and such systems are being developed for many crops.

A management system for the protection of winter wheat is already operational. Decision making in this management system concerns the control of the pathosystem by applying a pesticide only when needed. The decisions require information on the cost/benefit relation of a prospective treatment. Total costs depend on the price of the chemical, labour costs and possible damage to the crop by chemical or spraying equipment. Damage caused by the spraying equipment (mainly wheel-track damage) depends on the past and present state of the particular field, and is not affected by the pest or disease. The benefit of a treatment depends on how the disease is affecting crop productivity. This may vary from field to field, so that information on both crop and pathogen is needed for each individual field.

Comprehensive explanatory models have shown that in cereal diseases the upsurge of the epidemic is decisive for the amount of damage that may occur later in the season, and that in this very first phase the severity of the disease increases exponentially, as growth limiting factors are absent. The relative growth rate is used as a value to characterize the host-pathogen relationship. This relative growth rate may depend on the development stage of the crop, crop conditions (e.g. nitrogen status) and weather conditions. The severity of the disease in the (near) future, is estimated using a certain time horizon or prognosis period. Future severity is used to compute the expected yield loss. The computation of yield loss may be based on an analysis as given in Sections 4.3 and 4.4.

The types of analysis, given in the previous Sections, were used to construct a supervised disease and pest control system in winter wheat: EPIPRE.

5.1.3 EPIPRE, a supervised control system of pests and diseases in wheat

EPIPRE, developed in the Netherlands, is a system devised to support decision making in pest and disease control in winter wheat. It is an acronym representing EPIdemiology, PREdiction and PREvention. EPIPRE is one of the earliest world-wide attempts to develop computerized Integrated Pest and Disease Management systems (IPDM). The word integrated has a double meaning here. EPIPRE integrates chemical control with various aspects of varietal choice, crop husbandry, and farm economics. It also integrates the control of six fungal diseases and three aphid pests (Table 32; Zadoks, 1981). Moreover, the aim of EPIPRE is to minimize cost of crop protection measures and to reduce pesticide use.

Field monitoring EPIPRE's comparative advantage is its field specificity (Zadoks et al., 1984). Each field is registered separately, with its own characteristics, and each field must be monitored for pests and diseases. EPIPRE requires the participants to do their own monitoring, for two reasons. The first is educational, the participants should learn how to diagnose their own situations. The second reason is a formal one. With computers, it is 'rubbish in, rubbish out'. To avoid this, it is the responsibility of the participant to provide good input data, and the responsibility of the management to provide good output data from these inputs. Some input errors can be recognized and corrected, but many cannot. An error-spotting algorithm has been in use. The output returned to the participant repeats the original information, as used by the computer, so that the participant can check the inputs used.

Table 32. Pests and diseases on wheat considered by EPIPRE. Diseases not mentioned in this table cannot yet be controlled satisfactorily, and thus are not handled by EPIPRE.

Latin name	Common name
Erysiphe graminis	Powdery mildew
Pseudocercosporella herpotrichoides	Eyespot
Puccinia recondita	Brown rust
Puccinia striiformis	Yellow rust
Septoria nodorum	Glume blotch
Septoria tritici	Leaf blotch
Aphids were treated as a group	
Metopolophium dirhodum	Rose-grass aphid
Rhopalosiphum padi	Bird cherry oat aphid
Sitobion avenae	English grain aphid

Field monitoring takes time, and time is money. About half an hour per field, spent on monitoring, seems to be acceptable to most farmers, if it does not have to be done too frequently. In 1983, the average number of visits per field was 4.2 h ± 1.5. The costs of the farmers' time, which are relatively independent of field size, were incorporated into the module calculating the net profit according to EPIPRE. For the Netherlands, with an average field size of 8 ha, this means an observation time of no more than half an hour per ha; the production of 1 ha of winter wheat, including all agronomical activities, requires about 8 h ha^{-1} under Dutch conditions.

Implementation Implementing EPIPRE is a complex affair. The actual program, presented in a modular design, varies with time, conditions and available computers. Only a few points will be raised here, by way of example, according to the 1985 version (Reinink, 1985).

When EPIPRE was initiated, the standard objection made by scientists, but not by farmers, was 'we don't know enough'. The standard reply was 'we use whatever knowledge is available here and now'. This reply is still valid, but how much should we 'know' for decision support systems in IPDM? Too much knowledge may result in the system designer going out of business. He simply does not need to know the financial implications of every possible situation, because the majority of these possible situations (e.g. with very little or very much disease) are, in any case, not very interesting (Zadoks, 1984).

A prerequisite for the designer of a decision support system is a good understanding of the decision making process (Norton & Mumford, 1983). Complex simulation models, highly detailed and thoroughly verified, are splendid research instruments but clumsy extension tools (Zadoks & Rabbinge, 1985). They are too complex and too slow, require too many specifications and provide unnecessary detail for decision making. Also, they are often not available.

For extension purposes, the model should be as simple as possible. So, why use sophisticated equations when the exponential equation, well known from population dynamics, has been proved to be good enough in the situation considered? Population density studies are only of importance during the very first phase of population growth, when exponential growth occurs. Moreover, predictions are made for relatively short prognosis periods, so that updating the input data obtained by monitoring is possible.

The decision maker has, at any time, only two options, he either treats or he does not. However sophisticated the model, which in EPIPRE is nothing more than a deterministic yes/no decision model, it must determine the 'action threshold' (Zadoks & Schein, 1979), where *no* just tops over into *yes*. The actual course of disease is of no interest to either the system designer or to the decision maker, except to determine whether or not the disease will pass the action threshold (Zadoks, 1985). The quality of a decision support system does not depend on the amount of underlying knowledge, but on the frequency of its usage and the profits made by using it.

The pragmatism expressed here does not exclude sound biological knowledge from decision support systems. In EPIPRE, the model status, the amount of biological knowledge incorporated into the model, varies according to the disease being considered. The following briefly indicates, in descriptive and subjective terms, the model status of the various modules of EPIPRE (Reinink, 1985).

Yellow rust The module is based on the oldest European disease simulation model, now outdated. Adequate knowledge of the effects of cultivars, sowing dates, soil types, and fungicides was absent, so that all the parameters had to be estimated by a process of iteration. The resulting model was extensively checked by repeatedly visiting hundreds of fields.

The underestimation of future severity occurs when the distinction level is less than 99.5% or $p < 0.005$ and is corrected at the next observation round. Early samples of yellow rust were used to examine the physiological race involved and to adjust the system before a new race appeared.

Brown rust Little effort was made to model the dynamics of brown rust. However, detailed disease and damage assessment studies have been made in recent years by R.A. Daamen (unpublished), which were applied to the brown rust module.

Powdery mildew The early model, based on the yellow rust module, has been gradually upgraded. Recently, a great deal of knowledge on disease assessment (Daamen, in prep.) and damage assessment (Daamen, in prep.) has been collected and applied to EPIPRE. The mildew model also uses recent knowledge about the physiology of damage caused by powdery mildew (Rabbinge et al., 1985). A special algorithm was developed to warn of unexpectedly severe mildew infestations after treatment, which could be due to the resistance of the mildew to triadimefon (de Waard et al., 1986).

Eyespot Although interesting decision models are available from elsewhere, use is only made of the Dutch extension service. The action threshold at development stage DC 31 (Decimal Code, Zadoks et al., 1974) is about $x = 0.15$, adjusted for variety, DC and expected yield. On sandy soils, no treatment is recommended to avoid stimulation of sharp eyespot (*Rhizoctonia cerealis*). On other soils, treatment is avoided wherever possible to reduce carbendazim resistance in the fungus (Sanders et al., 1986).

Septoria EPIPRE lumps all brown flecks on leaves under the heading *Septoria*, to compensate for the limited diagnostic abilities of the participants. *S. tritici* (*Mycosphaerella graminicola*) and *S. nodorum* (*Leptosphaeria nodorum*) are then 'separated' by means of an algorithm, based on annual disease surveys providing relative frequencies of the two diseases per region and soil type. Treatments recommended only once between crop development stage stem extension and watery ripe, DC 39 and DC 69 respectively, are most effective at about DC 57. The two diseases respond differently to the various fungicides. Information on damage is available (Forrer & Zadoks, 1983). For *S. nodorum*, ear infection must be avoided. On some sandy soils, severe ear infection may appear without any noticeable infection of the leaves in earlier development stages.

Aphids The aphid model in EPIPRE is well substantiated. Aphid monitoring has been studied in detail (Rabbinge & Mantel, 1981; Rabbinge & Carter, 1984; Ward et al., 1985a, b) and explanatory simulation models have been constructed for aphid population biology (Carter et al., 1982). The physiology of aphid damage is well known (Rabbinge et al., 1983, 1984a). In the aphid module, this knowledge is compacted into simple algorithms. Before DC 55 the action threshold is 0.7 (expressed here as the proportion of tillers with at least one aphid; $x = 0.7$). At late milky ripe, DC 77, damage is negligible and no treatment is recommended. After booting, DC 55, and before late milky ripe, $55 < \mathrm{DC} < 77$, treatment is never recommended if the proportion of infested tillers is less than 0.2, but always if this proportion is higher than 0.80. In the remaining interval, a calculation is needed. This is done in a similar way to that for the diseases with a superproportionality correction (Section 4.4). The expected damage increases, and is expressed in grain weight from 18 to 80 kg ha^{-1} for each aphid tiller^{-1} at the maximum population density when yield increases from 5500 to 9000 kg ha^{-1}.

This summary of the various EPIPRE modules leads to the conclusion that detailed, explanatory simulation models are useful but not indispensible prerequisites for applied IPDM. It is the underlying biological knowledge that is required, and this can only be obtained by combining modelling with experimental work.

Multiple infection The decision is simple as long as only one disease passes the action threshold. It is complex when several diseases become significant growth- and yield-reducing factors. Then it is necessary to find the best combination of pesticides. Sometimes, two or more diseases are subliminal but, nevertheless, a combination treatment is warranted. Alternating pesticides, to avoid the development of resistance in fungi to fungicides, is then considered and only those aphicides which do not harm beneficial insects, and which respect before-harvest safety periods, are recommended.

How a decision is made The EPIPRE data bank contains field data and general data. The field data are specified by the farmer for each field separately (Table 33). They contain core data, once per season, and variable data, from two to five observation dates per season. The field observations made by the farmer follow a certain protocol (Figure 75) and lead to completing an Observation Card (Figure 76). This card contains farmer and field identification data and the variable data, used as inputs for EPIPRE. EPIPRE responds with a written recommendation (Figure 77) previously sent by mail, but nowadays replaced by a telephone call.

The general data belong to various groups. One group is a list of some 60 varieties with their susceptibility coefficients (Table 34). Another group is a list of some 150 commercially available pesticides with their characteristics and prices. A third group consists of a large set of small tables for operational use by the several EPIPRE modules. A fourth group contains the texts of the recommendations to be given.

Table 33. Field data used in EPIPRE. (Source: Reinink, 1985).

Variable data	Core data
1. Date	1. Variety
2. Growth Stage = DC	2. Soil type
3. Counts of:	3. Yield expectation
Eyespot	4. Width of spray swath
Yellow rust	5. Labour costs for treatment
Brown rust	6. Costs of pesticides
Powdery mildew	7. Number treatments after 15 May
Leaf flecks (Septorias)	8. Dates/amounts CCC treatment
Aphids	9. Dates/amounts N treatment
4. Recent treatments applied	

Walk over the field in a diagonal line. On 20 locations check 5 stems for the presence of aphids and take 2 stems for disease assessment. For aphid assessment (from DC 49), count the number of stems with at least 1 aphid. Use the 40 stems for the following assessments:

- Determine the development stage using the Decimal Code (Zadoks et al., 1974).
- Eyespot disease, until DC 32. Count the sprouts (stems) with eye spots. The range is from 0 to 40.
- Yellow rust. Inspect the 5 upper leaves of the stems and count the leaves with at least 1 lesion. If 5 leaves per stem are not left, inspect only the green leaves. The range is from 0 to a maximum of 200.
- Brown rust. As yellow rust.
- Powdery mildew. Inspect the upper 3 fully grown leaves of the stems and count the leaves with mildew. The range is from 0 to 120.
- Brown leaf fleck, after DC 39. Inspect the upper 3 fully grown leaves of the stems and count the leaves with brown flecks. The range is from 0 tot 120.

Figure 75. Schematic protocol for field monitoring.

EPIPRE Observation Card

FIELD NR.: VARIETY:
FIELD NAME:

Date: Growth stage:

Eyespot	Yellow rust	Brown rust	Mildew	Leaf flecks	Aphids

TOTALS from scoring list on reverse side

Figure 76. Example of an EPIPRE observation card, to be completed by the farmer.

Wheat cropping system EPIPRE recommendation

FIELD
NAME: Nearfield

FIELD
NUMBER: 1312

Variety: Arminda

Lelystad, 8 June 1986

Considering your field observations of 7 June 1986,

Disease	Count	Damage and costs in kg wheat per ha			
		Expected damage	Labour	Wheel track damage	Costs of pesticides
Yellow rust	16	Over 500	40	101	107
Brown rust	0	0	40	101	138
Mildew	0	0	40	101	107
Leaf flecks	17	Over 500	40	101	43

We advise you to treat on or shortly before 13 June 1986.
The treatment should aim at
LEAF FLECKS and YELLOW RUST
The ultimate date for the next field observation is 27 June 1986.
We recommend using one of the following pesticides or combinations:
BAYFIDAN, CORBEL or TILT in combination with SPORTAK.

Figure 77. Example of an EPIPRE recommendation.

All possible recommendations have a code number, following a binary numbering system. The code number is calculated from the Decision Module. From its data bank, the computer finds the corresponding text to be sent to the farmer. There are three possibilities per disease: (1) Expected loss is less than the pesticide costs. No treatment is recommended. If there is disease, the date of the next observation will be indicated. (2) Expected loss exceeds the costs of the pesticide but is less than the total treatment costs. A recommendation for treatment is

Table 34. Susceptibility coefficients of varieties.

Disease	Range
Aphids	not used
Eyespot	80–110
Brown rust	77–110
Powdery mildew	70–120
Glume blotch	88–100
Leaf blotch	88–100
Yellow rust	77–100

considered, in combination with other possible treatments. (3) Expected loss exceeds the treatment costs. A recommendation for treatment is given. If a treatment has already been applied, the program will respect the duration of the effective protection period.

The annual variation in the mean number of recommendations is considerable (Table 35), mainly due to variations in long-term weather patterns. The steady replacement of varieties, and the gradual improvement of EPIPRE, may also have affected the annual variation.

Procedures The effect of disease intensity on damage and loss (Zadoks, 1985) depends on the development stage of the crop. All calculations are based on the development stages described by the Decimal Code (Zadoks et al., 1974). The following procedural aspects refer to the yellow rust module and reflect the structure of the other modules. Each disease or pest in the system has its own module, with basically the same structure.

The field observation produces a figure n with $0. \leqq n \leqq 200$, i.e. the number of leaves from 200 inspected leaves with symptoms. This incidence number n is transformed into a disease severity by using the relation between severity and incidence. The disease severity, y, expressed as a fraction of visibly diseased leaf area is, at the low severity levels of interest here, proportional to n:

$$y_0 = 0.00025 \cdot n$$

Expected disease severity, expressed as a fraction y_e $(0 \leqq y_e \leqq 0.1)$, is the disease level expected at some time in the future. Starting with the present observed disease level, y_0, the future disease level, y_e, is foreseeable only over a short time horizon, the prognosis time, t_p. The prognosis time, t_p, (Table 36) depends on crop development stage, DC. Development rate is directly affected by mean temperature. The exponential equation for disease increase is

$$y_e = y_0 \cdot \exp(t_p \cdot r_e) \qquad \text{Equation 120}$$

Table 35. Annual variation in recommendations. Entries represent percentages of fields for which farmers were recommended to treat the disease mentioned in the first column. Also given are the annual mean number of spray recommendations per field for all diseases together, the annual mean recommended Treatment Index (TI represents the actual number of recommended machine runs per field applying pesticides either singly or, more usually, as a mixture), and the total number of fields involved. (Source: Stol, 1985).

Disease	Year			
	1982	1983	1984	1985
Eyespot	–	6	10	19
Yellow rust	0	8	3	2
Brown rust	0	18	3	5
Powdery mildew	13	63	99	53
Septorias	11	37	37	48
Aphids	51	3	38	44
recommendations per field	4.1	3.8	4.8	4.5
recommended TI	0.8	1.6	1.9	1.6
number of fields	1069	1380	1100	816

Table 36. Yellow rust. Prognosis time (t_p) and relative growth rate (r) in relation to development stage, DC. (Source: Reinink, 1985).

DC	t_p	r	
		without N top dressing	with N top dressing
37	28	0.110	0.110
39	28	0.109	0.124
45	23	0.105	0.121
59	16	0.088	0.102
69	6	0.074	0.087

The relative growth rate, r_e, of a disease depends, for example in stripe rust, on variety (susceptible or not), DC and nitrogen status (Table 36). Varieties are placed in one of three groups, susceptible with a compatibility coefficient CF = 1., moderately resistant with CF = 0.88, or resistant with CF = 0.77. A cultural correction (CC) is applied to express the effect of cultural conditions on the disease, e.g. for spring wheat CC = 0.82. The expected relative growth rate, r_e, is found by multiplication:

$$r_e = r \cdot CF \cdot CC$$

in which r expresses the relative growth rate under optimal conditions. This value is inserted into Equation 120 to obtain the expected severity.

When a treatment is applied, y_e can be reduced by systemic action and t_p by protectant action of the pesticide. Reduction factors RF must be introduced. Equation 120 becomes

$$y_e = y_0 \cdot RF1 \cdot \exp(t_p \cdot RF2 \cdot r_e)$$

Reduction factors may vary per disease and cultivar. The varietal resistance can strongly influence the effectiveness of systemic fungicides. As the literature is rather 'silent' on reduction factors, they are determined empirically using an iterative approach.

As very low levels of disease cause relatively little damage, a no-damage discount y_n (Table 37) is applied to y_e. The expected damage, d_e, is expressed as a multiplier m, again DC-dependent (Table 37). In some cases, damage at high yield levels, resulting from favourable growing conditions, such as high nitrogen levels, is superproportional; i.e. more than proportional to yield (Rabbinge et al., 1981; Rabbinge & Rijsdijk, 1984; Section 4.4). Superproportionality is attained by introducing a factor s, which equals 1.0 up to $Y_e = 7500$ kg ha^{-1} and increases linearly up to $Y_e = 8000$ kg ha^{-1}, Y_e being the expected yield specified by the farmer. The expected relative damage, d_e, expressed as a proportion of the expected yield, becomes

$$d_e = y_e \cdot m \cdot s$$

The expected damage D_e, expressed in kg ha^{-1}, is d_e multiplied by the yield expectation, Y_e in kg ha^{-1}:

$$D_e = d_e \cdot Y_e$$

Table 37. Yellow rust. No-damage thresholds (y_n) and damage multipliers (m) depending on development stage, DC. (Source: Reinink, 1985).

DC	y_n	m
30	0.002	5.0
39	0.002	6.7
45	0.002	5.0
61	0.005	2.0

This value is transferred to the decision model, where it is balanced against expected costs.

Data management A decision scheme that uses specific field and crop data, as in EPIPRE, requires structured data storage and management. It is necessary to describe the site characteristics accurately to generate the recommendations. The continuously changing situation during the season is partly due to the growth and development of the crop and pest and disease populations, and it is partly due to man, through cultural measures such as the application of fertilizers, growth regulators and pesticides. Whenever a recommendation is generated, a check of the data is needed which will include the effects of changing parameters. In EPIPRE, data are organized as follows: basic data, being parameters which do not change during one season, such as soil type, variety, farmer's address etc.; fertilizer data, which are added during the season; data on pesticides, which are added during the season; observations, together with recommendations based on these observations. During the season, a data-base is filled gradually, starting from the basic data and finishing with a more or less complete field and crop history. These data can be used afterwards to check any complaints from the farmers, and for scientific analysis, which may lead to improvements of the system.

The techniques of data management will not be treated here. It suffices to recommend modern data-base software packages which enables the easy storage and retrieval of data from a data-base. Many software packages are available, ranging from indexed file systems to well-defined and completely preprogrammed data management systems, such as CODASYL or Relational Database systems.

5.1.4 Pathosystem management as part of crop management

Using EPIPRE, we have demonstrated how a decision system with complex decision algorithms can be developed, and how it can make use of information on crop husbandry practices. It indicates a new line of future developments. Pest and disease management systems must be part of an integrated crop management system, covering all decisions made by the farmer. Some crop management systems (e.g. on small grains) are now ready for experimental use in agricultural practice. These crop management systems are in fact collections of advisory modules which cover most farmers' decisions. They may improve decision making and, in many situations, lead to the reduced use of pesticides.

At present, these decision support systems are run on mainframe computers, which means that the system is completely centralized. However, EPIPRE can also be run on microcomputers, completely decentralized. The advantages of centralization are, rapid updating and upgrading of the system and immediate contact between user and adviser, but time consumption and communication limitations are a disadvantage. On the other hand, decentralized systems have the disadvantage of slow updating and no guaranteed upgrading.

Another development concerns the introduction of packages in which farmers may choose between various forms of risk-accepting and risk-avoiding behaviour (Section 5.2). This development of steady improvement and upgrading of supervised control systems tends to increase the scientific basis of crop husbandry. Therefore, in the near future, we will see crop management systems where all aspects of crop management are integrated. For their development, much additional interdisciplinary scientific work is needed in which simulation models may play a major integrative role.