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# 15 Monitoring and Forecasting of Cereal Aphids in the Netherlands: A Subsystem of EIPPRE

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## 15.1. INTRODUCTION

Cereal aphids have become increasingly important pests in Western Europe; during the last few years losses have often exceeded 1000 kg/ha of wheat. Much of this damage is caused by secondary effects, since the actual loss of sap caused by aphid feeding is only of minor importance in plants growing under optimal conditions. Model calculations, confirmed by experimental measurements, show that the major reason for damage is honeydew produced by the aphids, which covers the epidermis, limits CO<sub>2</sub> diffusion, and probably promotes leaf senescence (Rabbinge and Vereijken, 1979; Carter and Dewar, 1981; Vereijken, 1979). This type of damage also explains why there is such a low correlation between aphid load, whether expressed as maximum number or as aphid days (integrated aphid numbers throughout the infestation period) and yield loss ( $r = 0.69$ ,  $n = 21$ ; Figure 15.1). This low correlation makes the definition of fixed damage thresholds impossible, and the prediction of expected yield losses possible only when more quantitative knowledge of the dynamics of aphid-host plant interrelations are included. Detailed studies of these damage effects have shown the complex nature of the yield losses, and have also demonstrated that the role of ants as mutualists of aphids is irrelevant, but that saprophytic fungi on the honeydew may have considerable effects.

Three species of cereal aphid are usually involved: the English grain aphid (*Sitobion avenae*), the rose grain aphid (*Metopolophium dirhodum*), and the bird cherry-oat aphid (*Rhosalosiphum padi*). *S. avenae* is generally considered the most important; it prefers to feed on wheat ears, where it interferes with the translocation of assimilates to the kernels. In 1978 and 1979, however, cereal losses exceeded 1000 kg/ha, caused mainly by large numbers of *M. dirhodum*, while *S. avenae* was uncommon.

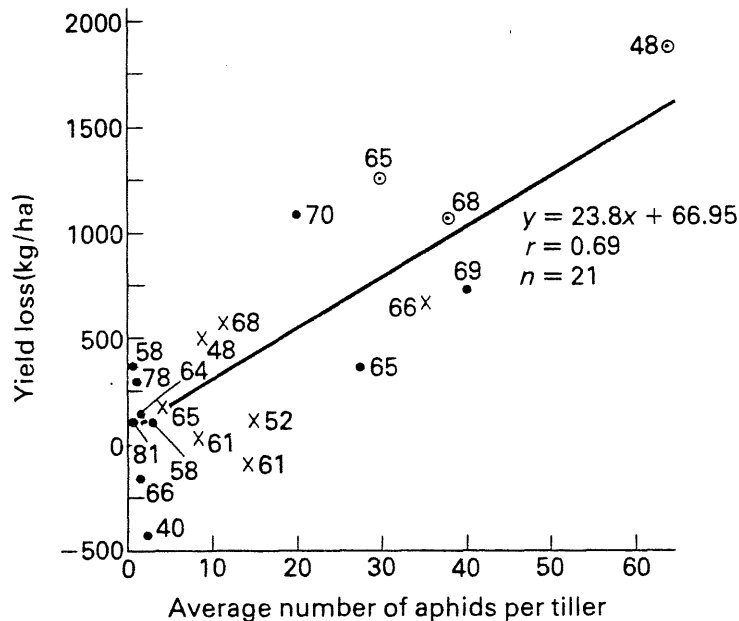


FIGURE 15.1 Yield loss as a function of the peak number of aphids per year. • more than 80% of *M. dirhodum*; × more than 80% of *S. avenae*; and ⊙ both species present; numbers represent the yield in the control ( $\times 10^2$  kg ha<sup>-1</sup>)

Yield losses of this size caused by aphids frequently occur in Europe, probably due to the considerable changes in wheat cultivation during the last decade (Potts, 1977). High sowing densities, early sowing times, large applications of split nitrogen, and the use of growth regulators and control measures for leaf and ear diseases have resulted in wheat yield levels approaching about 10 000 kg/ha. These high production levels depend on a healthy wheat crop with an extended maturation period of three or four weeks.

Each day lost in kernel filling and ripening will decrease the yield by 200 kg/ha. The management strategy of many Dutch farmers is to keep crops free of diseases during spring and early summer, so that after flowering a sound crop will start kernel filling. Accordingly, pesticide use in wheat crops has had to be greatly increased to protect the crop up to flowering; spray applications using fixed schedule schemes have, in some places, resulted in five or more treatments of fungicides, insecticides, and herbicides being applied.

The EPIPARE system was initiated to prevent further increases in pesticide usage on wheat, thus reducing the chance of problems associated with insecticide resistance encountered in other crops, such as cotton and apples. The EPIPARE system, which is discussed further in Chapter 21, aims at flexible crop protection, based on detailed knowledge of crop growth and the prevailing pests and diseases. By integration of this knowledge in large

computer systems, dynamic decision rules have been developed that are used in the field to indicate when spraying is really necessary, i.e., when yield gains will balance the cost of pesticides. This flexible response system limits pesticide use but requires highly developed knowledge of intensive plant protection systems. These might replace other rigid systems in which pesticides are applied according to schedules. At present, field experiments and dynamic crop-pest simulation models are being used to develop dynamic threshold levels; in the course of time these will be combined with a system of aphid monitoring and forecasting to develop a reliable warning and pest control system.

In this chapter we outline the model we have developed for the principal wheat aphid *S. avenae*. Validation and sensitivity tests suggest a reasonable degree of realism and also indicate the critical variables in the system. Good model performance depends on accurate monitoring of aphid density at flowering and subsequent aphid immigration, and we discuss how these are obtained and incorporated in the model. Finally, we describe the decision procedure based on the model.

## 15.2. APHID BIOLOGY

In 1978 and 1979 *M. dirhodum* was the most common aphid species on cereals. It overwinters in the egg stage on roses. The fundatrigenae (founder adults) are either apterous (wingless) or alate (winged), but the third generation is completely alate (Hille Ris Lambers, 1947), and can also overwinter viviparously on grasses and cereals (Dean, 1978; George, 1974). Once it has migrated to cereals it feeds on the leaves, moving up the plant as the crop develops. As the crop flowers this species stays on the leaves, mainly on the flag leaves, especially in the short straw varieties. Its absence on the ear is the major reason why many researchers consider it less important than *S. avenae* in causing yield losses.

*R. padi* is the most important vector of barley yellow dwarf virus, a disease that up to now has not been important in Western Europe and is therefore not considered in this study. *R. padi* is one of the commonest aphids caught in suction traps in Europe, and is a potentially serious pest, but it is only important in Scandinavia (Markkula, 1978). It can overwinter either on bird cherry in the egg stage, or viviparously on cereals and grasses. Fundatrices hatch from eggs in April, around the time of bud-burst (Dixon, 1971). The number of aphids increases rapidly and many alates are produced that colonize grasses. *R. padi*, like *M. dirhodum*, settles on the leaves but it is also encountered on the ears and stems.

*S. avenae* is monoecious on Gramineae, on which it may overwinter as viviparae or as eggs, but very little information is available on the relative importance of the methods (Dean, 1974). It is usually very difficult to find

either *S. avenae* aphids or eggs on grasses in winter, so that it is impossible to monitor spring populations for use in an early warning scheme. Alates usually colonize winter wheat in preference to most other cereals, from the end of May until the end of June (Carter, 1978), and are caught in suction traps before they are encountered in the field (George, 1974). At the start of immigration the wheat has not headed and the alates settle on the leaves. As the ears emerge they are colonized by the alates and their nymphs. Most of these nymphs develop into apterous adults whose reproductive rate is higher than that of the alate adults and hence population growth is maximized (Wratten, 1977). The reproductive rate of *S. avenae* is higher on the young ears (up to the end of the watery ripe stage) of cereals than on the leaves or the older ears (Vereijken, 1979; Watt, 1979), and its survival rate is also highest on these young ears (Watt, 1979). As the aphid density rises and the crop ripens an increasing proportion of the nymphs born to these apterae develop into alate adults. Also, as the aphid density increases the reproductive rate decreases, and this contributes to the population decline. From the milky ripe stage onwards, alates leave the crop, resulting in a rapid decline in field populations and also by the large catches in suction traps at this time. This emigration is probably induced by a combination of the high aphid densities, by the ripening of the crop, and possibly by the large numbers of natural enemies in the crops, which destroy any remaining aphids.

#### 15.2.1. Natural Enemies

These can broadly be divided into four groups: aphid-specific predators, polyphagous predators, parasitoids, and fungal pathogens. The aphid-specific predators (Coccinellidae, Coleoptera; Syrphidae, Diptera; Chrysopidae, Neuroptera) are usually rare before flowering but their numbers increase after this stage. Only occasionally are their numbers very high. The contribution of these predators to population control of cereal aphids is limited although the few detailed studies of natural enemies using cereal aphids as the prey indicate that their predation capacity is high. The fourth and most voracious instar of *Coccinella 7-punctata* consumes 40 third instar *S. avenae* nymphs per day at 20 °C (McLean, 1980). The predation capacity of *Syrphus corollae* is even higher and amounts to 200 L1–L3 larvae of *S. avenae* or 100 fourth instar larvae (Bombosch, 1962). The searching capacity of this predator is low, however, and it immigrates late. The predation activity of *Chrysopa carnea* is of the same order of magnitude but it is even less common than the Syrphidae and Coccinellidae, the latter group being common at some places at the very end of kernel filling.

Potts and Vickerman (1974) stress the importance of polyphagous predators in controlling aphid populations; if they are already present in fields when aphids arrive they could reduce aphid numbers considerably and thus prevent

outbreaks. Potts (1977) and Vickerman and Sunderland (1977) have noted that these predators are declining in cereal fields in the UK, perhaps due to the increasing use of pesticides. There is very limited information available on the searching behavior or consumption rates of these predators. To evaluate their quantitative effect in aphid control more detailed studies on their predation characteristics should be carried out.

Parasitoids belonging to two families of Hymenoptera: Aphelinidae and Aphidiidae, are always present in cereal fields. The latter group is the more important one in Europe. The numbers and dominance of each species is different each year. For example, in the Netherlands the parasitoids found in 1976 were, in order of abundance, *Aphidius uzbekistanicus* (type), *Praon volucre*, and *A. picipes*, while in 1977 the order was *A. ervi*, *A. picipes*, and *A. uzbekistanicus* (type). Their effect is usually limited due to their low numbers early in the season and the high proportion of hyper-parasitism.

Late in the season fungal pathogens of the aphids may occur, belonging to the genus *Entomophthora*. Especially when weather conditions are suitable the fungal disease may become epizootic and contribute to the collapse of the aphid population.

### 15.3. MODELING

#### 15.3.1. Description

Two models to simulate the population development of *S. avenae* have been developed independently in the UK (in FORTRAN IV; Carter, 1978) and in the Netherlands (in CSMP III; Rabbinge *et al.* 1979). A simple diagram for the development of *S. avenae* is given in Figure 15.2. Juvenile aphids with three larval stages develop into alateform or apteriform L4. The maturing apterous females may produce a new generation of aphids, whereas the alates emigrate and disappear from the system. Wing formation is a result of the combined effects of crowding and the stage of the plant, and is introduced as such in the population model. Further studies of these effects have been made in the laboratory, although these are still of a preliminary character and the results are not very consistent. The influence of temperature on development reproduction rates is shown in the relational diagrams by the arrows from the driving variable, temperature, to the rates. These relations are derived from Dean's (1974) data and our own experiments using young wheat plants as a food source instead of barley leaf disks on wet cotton wool. Dispersion during development and its dependence on temperature are introduced in the Dutch model. For example, larvae of the same age are reproductive at different times. A special "boxcar" routine is developed with which growth through different stages is mimicked. This subroutine mimics the dispersion in time during development and ageing and adapts it to external conditions. Basically, this is

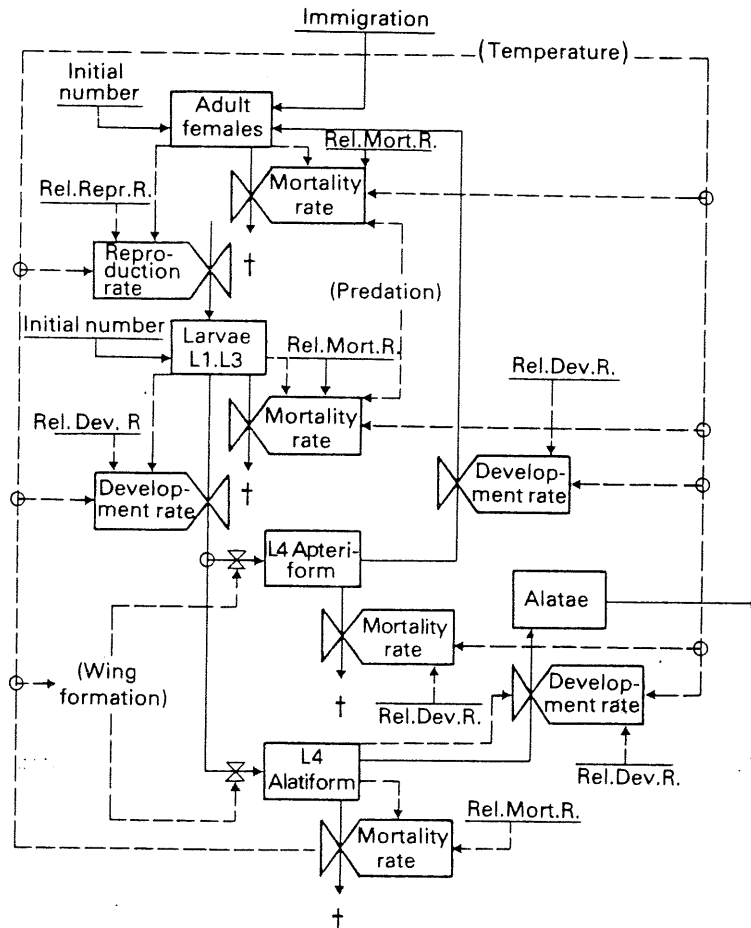


FIGURE 15.2 Relational diagram of population growth and development of *S. avenae*.

done by distinguishing artificial age classes within the morphological age classes, which are reached at different rates. Dispersion, however, seems to be of minor importance, as indicated by sensitivity analysis. The relatively small size of the standard deviation explains this.

Both models simulate aphid population growth up to the time of its collapse. The period before the aphids migrate into the winter wheat fields and the winter period are not taken into account. The models are started with the first numbers of aphids in the crop or suction trap catches, respectively. Initial inputs are maximum and minimum temperatures, latitude of the site, initial stage of crop development, initial numbers of aphids and natural enemies, and migration data. From then on, population growth is simulated numerically using time steps of one hour or 15 minutes; this latter is determined by the

smallest time coefficient of the system, in this case dictated by the developmental period of the aphids at 30 °C. Temperature and crop stage are the major driving forces of the model. The temperatures are calculated at each time step using a sine curve passing through the daily maximum and minimum temperatures. The stage of development of the crop is updated by integration of a temperature-dependent development rate. To run the models, data on the relations of reproduction, development, and mortality rates with morphological stage, crop development stage, temperature, plant conditions, and humidity are needed. Furthermore, data on the relations of the aphid and its natural enemies need to be introduced. The numbers of predators, syrphids and coccinellids, are simulated in the same way as the aphids. The predation and oviposition rates of these predators are introduced as the product of prey and predator density-dependent relative predation rates and the actual prey density. These relative predation rates of the predator (predation rate divided by prey density in the steady state) have been derived from Bombosch (1962).

The avalanche of data needed to start the models means that a compromise is necessary to prevent an endless series of process experiments. In the development of these models, modeling and experimenting go hand in hand. Model building results in calculations showing the decisive parts of the system where experimental emphasis is needed. This iterative way of model building may lead to a vicious circle so that careful validation procedures are required to circumvent this pitfall.

### 15.3.2. Validation of the Model

During model construction and experimentation several hypotheses, assumptions, and guesses were made on qualitative and quantitative relations within the system and on effects of forcing variables. To validate the structure of the model and the incorporated relations a comparison has to be made with the results of independent experiments. Moreover, a final analysis of the relative impact of different relations used has to be determined (sensitivity analysis).

Models have to be validated at different levels of integration. Data at the field level are available while data to verify the implicit hypotheses and model outcomes at lower levels of integration are still being collected. Population density curves for aphids of different instars and morphs are calculated by the models. Some results from the Dutch model are given in Figure 15.3, compared with actual field counts for different seasons at three locations in the Netherlands. The experimental data are given with 95% confidence intervals. For each year and location the simulated and observed total population density curves are in good agreement during the rapid growth phase. For nearly all simulated situations the age composition of the aphid population is also reasonably well simulated. The last part of the population

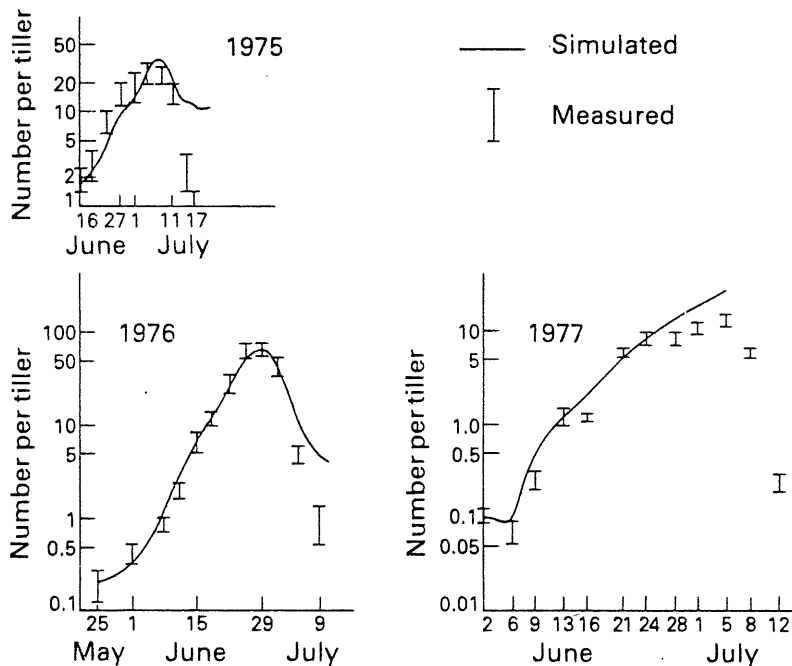


FIGURE 15.3 Simulated and actual numbers of *S. avenae* in 1975, 1976, and 1977. The actual numbers are given in terms of 95% confidence intervals.

curve is only reasonably simulated when there is a rapid decrease in reproduction and an increase in mortality rates (Watt, 1979; Vereijken, 1979).

The preliminary results of the simulated predator density in the Dutch model correspond reasonably well with field observations. This is encouraging, but it should be emphasized that the introduced relations on functional and numerical response of the predators are still based on estimates and incomplete experimental data.

The good overall agreement of model output and experimental results justifies a sensitivity analysis of the model. This serves both to improve our insight into the system and guide management and to pinpoint further laboratory or field studies that need to be done. The results of this sensitivity analysis show the following:

- (1) *The role of immigration in the population upsurge is different from year to year.* For example, the omission of immigration after flowering in 1976 had only a slight effect on the population density curve, whereas similar changes in 1977 caused a major effect on the population growth of the aphids (Figure 15.4).
- (2) *Emigration in combination with decreased reproduction and development and increased mortality are the major reasons for the flattening of the population.* An extended maturing period of the crop due to relatively cold weather and



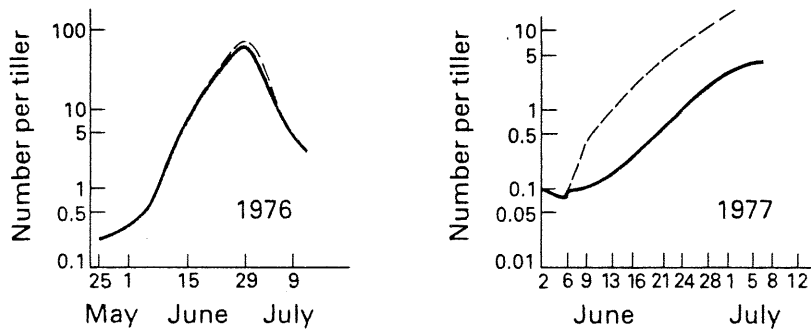


FIGURE 15.4 Effect of immigration on total number of aphids in 1976 (— without immigration; - - - - - basic curve); and 1977 (— without, and - - - - with immigration), according to the simulation model.

availability of sufficient nutrients may delay these effects and thus cause an extended period of infestation.

(3) *The quantitative effect of predators is limited in the population growth phase.* Only when natural enemies are present in considerable numbers at the beginning of the season, coupled with a clear preference for aphids and a high searching capacity, does the aphid population growth change. Since this rarely occurs the role of natural enemies is only important during the flattening and collapse of the aphid population. The contribution of predators becomes clearer in Table 15.1, where the simulated numbers of aphids lost per tiller due to predation in 1976 are given.

TABLE 15.1 Disappearance of aphids (numbers per tiller) in 1976 caused by predation, abiotic mortality, and emigration based on model calculations.

Date	Time	Growth stage of plant <sup>a</sup>	Mortality		Emigrants (winged females)	Actual number of aphids (total)
			Predation and parasitism	Abiotic		
24 May	5	10	0	0.001	0	0.3
29 May	10	10.1	0	0.004	0	0.4
	15	10.2	0	0.03	0	1.5
	20	10.3	0	0.05	0	5.6
	25	10.5.1	0.2	0.3	0.02	13.6
	30	10.5.2	4.0	1.0	0.27	40.6
	35	10.5.3	25.0	5.9	5.4	68.4
	40	11.1	99.8	12.2	20.0	22.3
9 July	45	11.1	119.6	13.3	24.1	5.0
	50	11.2	121.3	13.4	26.0	4.1

<sup>a</sup>Feekes scale.

(4) *Evaluation of the effect of initial conditions and the relations of the different rates with environmental conditions show that initial population densities around flowering may vary by at least 20% without having a considerable effect on population growth during the rest of the season.*

#### 15.4. MONITORING AND SAMPLING

*Model calculations have shown that knowledge of the population densities at the time of flowering suffices to start the simulation model and to predict the population upsurge when additional information on immigration is supplied. To assess the initial aphid population densities and the size of immigration Carter and Dewar (1981) describe how suction trap catches may be used to determine the amount and timing of immigration. These findings are now being compared with the number of aphids collected in the field using insect suction samplers. After immigration has started, farmers are advised to inspect their fields for aphids; these assessments may then be used to update the decision models of EIPRE and enable prediction on the course of the aphid population in time.*

Advice as to whether spraying is needed is based on the expected population peak and the still unreliable corresponding damage assessments (see Figure 15.1). Estimates of population densities should be found with simple but reliable methods that are not labor intensive. To derive such methods, the aphid distribution in the field was considered. In 200 out of 225 cases the aphid distribution fits a negative binomial distribution, with  $k$ -values ranging from 0.5 to 2. When average numbers are lower than 0.3 per tiller, determination of the distribution in the field requires more than 1000 tillers to be searched since the colonies are then scattered. Very rarely does a Poisson distribution give a better fit (20 out of 225 cases). Tests were made of the relation of the probit value of the infestation level and the logarithm of the average number of aphids per tiller of *S. avenae*, *M. dirhodum*, and *R. padi*, and combinations of these species. In all cases a linear relationship exists; see Figure 15.5 (correlation coefficients in all cases  $> 0.92$ ; number of cases  $> 225$ ). These linear relationships enable a simple, less labor-intensive sampling method to be used. The infestation level is determined, giving the average number of aphids per tiller that is used to start the decision model.

#### 15.5. THE DECISION PROCEDURE

*The procedure used in EIPRE is as follows. At flowering, farmers are asked to determine the aphid infestation level by inspecting 100 tillers taken at random over a diagonal of a field. When infestation levels are lower than 70%, farmers may delay any action for two to three weeks. At infestation levels higher than 70%, the economic damage level will be exceeded (350 kg of wheat/ha), and so farmers are advised to spray. The timing of the second observation by the*

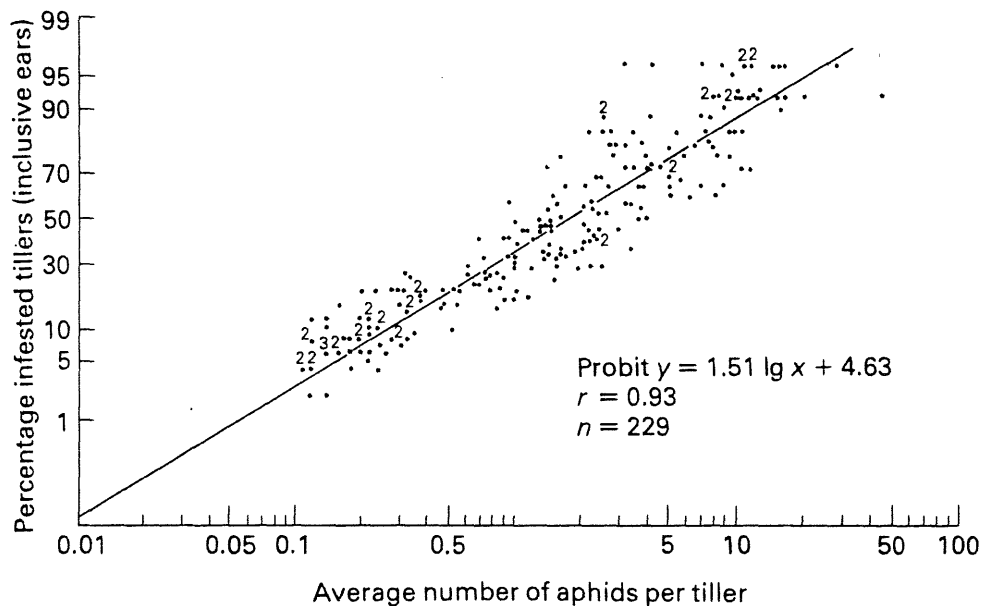


FIGURE 15.5 The percentage of infested tillers as a function of the average number of *M. dirhodum*, *R. padi*, and *S. avenae* per tiller.

farmer depends on computer calculations with the simplified simulation models. This period may vary from 10 to 20 days after flowering, at which time farmers are asked to determine the proportion of tillers with over ten aphids. These proportions, again after transformation, are linearly related to the average density per tiller. They provide supplementary information on the number of colonies, and the potential for emigration since population density is one factor that induces wing formation. All field data are sent to the forecasting research team on preprinted cards, and these are then used to make the decision on whether or not to spray.

The weakest point in the scheme is the determination of the damage threshold, since the timing of nitrogen top dressing and many other environmental factors may affect the actual damage. At present, therefore, threshold adjustment is more or less guesswork and additional research of the type discussed by Carter *et al.* (1982) is needed to solve these problems.

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