

A simulation model describing the population dynamics and damage potential of the rose grain aphid, *Metopolophium dirhodum* (Walker) (Hemiptera: Aphididae), in the UK

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Abstract

Metopolophium dirhodum (Walker) is occasionally a pest of cereals in the UK. A simulation model was developed to study its population dynamics and damage potential. The model was initiated by aphid immigration as measured by 12·2-m suction trap samples and with temperature as the major driving variable. It was validated with field observations from three contrasting years, 1979, 1985 and 1986. The model accurately predicted aphid populations and yield loss in a major outbreak year (1979) but was less accurate when densities were lower (1985 & 1986). Possible reasons for these discrepancies are discussed.

Introduction

Cereal aphids are important pests in Western Europe (Rabbinge & Carter, 1984), with large infestations causing losses in both yield and quality (Lee *et al.*, 1981). Forecasting outbreaks of cereal aphids is an important component in cereal pest management, and several schemes have been developed, mainly for *Sitobion avenae* (F.) (Rabbinge *et al.*, 1979; Carter, 1985; Wratten *et al.*, 1986). Less attention has been given to the rose grain aphid, *Metopolophium dirhodum* (Walker), although it too can reach pest status, e.g. in 1979. A simulation model was developed, based on information from the literature, to study its population dynamics and damage potential.

Model structure

A systems approach was used to list the factors thought to be important to *M. dirhodum* biology, and an interaction matrix was constructed (Holt *et al.*, 1987) (Fig. 1).

Immigration and emigration

The model simulated population development from the start of the migration by estimating the number of alates landing per shoot per day on cereals using samples from the Rothamsted Insect Survey suction traps (12·2 m) (Taylor & Palmer, 1972). The number of *M. dirhodum* landing per shoot (y) was dependent on the numbers of aphids in the daily

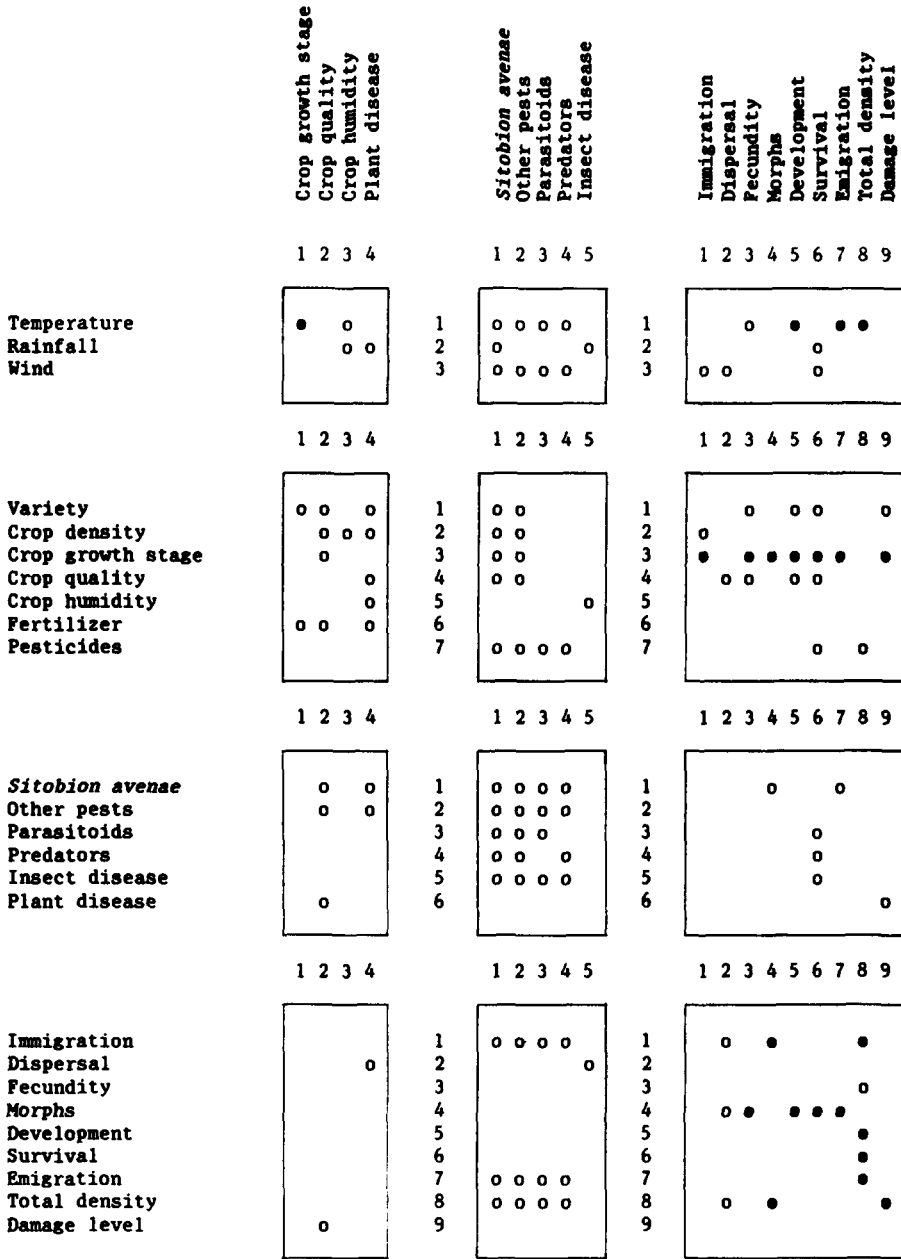


Fig. 1.—Relationships between components in the *Metopolophium dirhodum* system. (Symbols in cells indicate direct effects of row components on corresponding column components; ● represents relations between elements incorporated in the model; ○ indicates that relationships or interactions may exist but were not included in the model; blank cells indicate that no relationships were thought to exist between respective elements.)

suction-trap samples (s), a concentration factor (x , usually equal to 40 (Carter *et al.*, 1982)) and the number of shoots/m² (n):

$$y = (0.0237x/n)s \quad (1)$$

where 0.0237 was calculated based on assumptions of a density:height gradient of -1.0 , which is the regression coefficient of log density at a certain height (z) on log z , a flight time of two hours and random deposition such that each aphid in the trap corresponds to 237 aphids/ha (from Taylor & Palmer, 1972).

Suction-trap samples early in the season were assumed to consist entirely of immigrants, but later, as the cereals ripened, emigrants predominated. The proportion of immigrants (I) in suction-trap samples (I_c) was dependent on the current crop growth stage (S_c), the crop growth stage when emigrants first appeared ($C_1 = \text{G.S. } 77$ (Zadoks *et al.*, 1974)) and the crop growth stage when all alates were emigrants ($C_2 = \text{G.S. } 82$):

$$I = I_c \left(1 - \frac{S_c - C_1}{C_2 - C_1} \right) \quad (2)$$

Alates developing on the crops were assumed to emigrate immediately after moulting to the adult stage.

Development and survival

Plotting development rate ($1/\text{development time}$ (d_1 or d_2)) against temperature (t), using the data of Dean (1974), revealed two lines (Fig. 2, Equations 3 & 4) with the break at 20°C:

$$d_1 = 10^{-3}(0.522 + 0.24t) \quad (t \leq 20^\circ\text{C}) \quad (3)$$

$$d_2 = 10^{-3}(8.912 - 0.198t) \quad (t > 20^\circ\text{C}) \quad (4)$$

A low development threshold of -2.2°C was determined when the development rate (d_1) was equal to zero in Equation 3.

Daily maximum (y_1) and minimum (y_2) temperatures, which were assumed to occur at 14.00 h and sunrise, respectively, were used to calculate hourly temperatures (t_h):

$$t_h = (y_1 - y_2)\sin(\alpha + \beta h)/2 + (y_1 + y_2)/2 \quad (5)$$

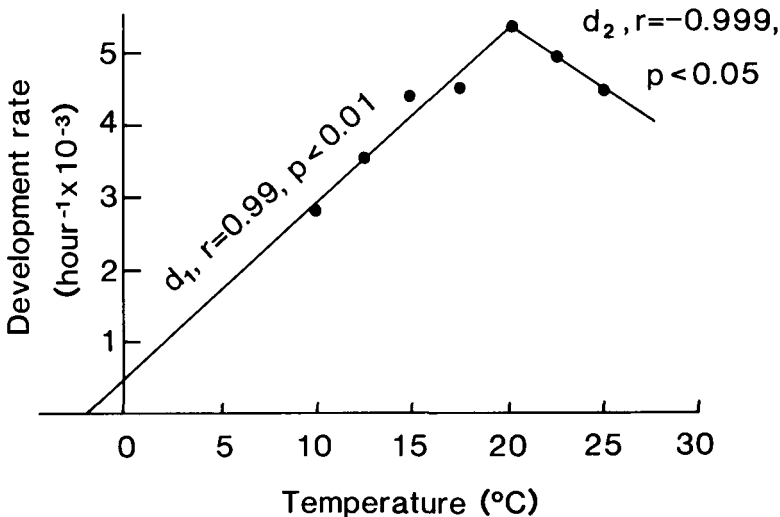


Fig. 2.—The relationship between development rate of *Metopolophium dirhodum* and temperature (after Dean, 1974).

where h is the successive hourly time throughout each day and α and β are constants determined by the time of sunrise.

Physiological time (p) was calculated using Equation 6 when the temperature (t_h) was less than or equal to 20°C and Equation 7 when the temperature was greater than 20°C:

$$p = t_h + 2.2 \quad (6)$$

$$p = d_1^{-1}\{d_2(t_h)\} + 2.2 \quad (7)$$

The development times of each nymphal instar and adult apterae (Dean, 1974) were calculated in hour-degrees above the development threshold of -2.2°C . The length of the alatiform fourth-instar nymphs was assumed to be 1.5 times that of the apteriform fourth-instar nymphs (Carter *et al.*, 1982). The lifespans of alate and apterous adults were dependent on crop growth stages based on the following assumptions: the values for development lifespans on seedlings (Dean, 1974) were used for the development time before the end of inflorescence (G.S. 59), when the crop growth stage was between the end of inflorescence and early milk (G.S. 73) apterous adults lived 0.2 times longer than that before the end of inflorescence, and, for crop growth stages greater than early milk, the adult lifespan was half that before the end of inflorescence. Alate adult lifespan was kept constant at half the apterous adult lifespan before the end of inflorescence.

Nymphal and adult survival rates of the apteriform morph were dependent on crop growth stage: 0.87 and 0.89 before early milk (G.S. 73) and 0.23 and 0.54 afterwards, respectively (Watt, 1979). The survival rates of the alatiform morph were assumed to be the same as those of the apterous morph.

Reproduction and morph determination

Reproduction rates were dependent on temperature, morph (alate or apterous) and crop growth stage. The rate per apterous adult per hour-degree was calculated from Dean (1974) and was the mean of the values at four temperatures (10, 15, 20 and 25°C). This value was reduced by 0.67 for crop growth stages before the end of inflorescence (G.S. 59) and increased by 1.2 for crop growth stages between the end of inflorescence (G.S. 59) and early milk (G.S. 73) (Thornback, 1981). The reproduction rate was assumed to be zero for crop growth stages after early dough (G.S. 83). Alate reproductive rates were those of apterous adults multiplied by 0.785 (Wratten, 1977).

The eventual morph of a nymph was dependent on aphid density (d) and crop growth stage (g) (Carter, 1985):

$$p_r = -27.189 + 2.603d + 0.847g \quad (8)$$

where p_r is the proportion of newly born alatiform nymphs.

Crop growth model

The decimal code (Zadoks *et al.*, 1974) was used to simulate winter wheat growth, using a polynomial equation between crop growth stage (C_c) and accumulated physiological time (tot) above a development threshold of 6°C (Carter, 1985):

$$C_c = 26.336 + 0.173tot - 0.000125tot^2 \quad (9)$$

Crop yield loss

The daily rate of yield loss (R_i) caused by *M. dirhodum* per aphid unit (one aphid unit is equivalent to three first- to third-instar nymphs, one fourth instar nymph or one alate or apterous adult) varied with crop growth stage (Wratten *et al.*, 1979, Lee *et al.*, 1981, Holt *et al.*, 1984). When the crop development was before the start of booting (G.S. 40), it was assumed that aphid infestations did not cause yield loss as the crop was able to compensate. The damage rates, as proportions of potential yield when uninfested, for other periods during the crop development was calculated from the literature (Table I). The rate was assumed to be zero after the early dough stage (G.S. 83).

TABLE I. Yield loss as a proportion of the potential yield per aphid unit day

Crop stage	Proportional yield loss	References or assumption
<G.S. 40	0.0	Assumption
G.S. \geq 40 - <55	1.556×10^{-4}	Holt <i>et al.</i> (1984)
G.S. \geq 55 - <60	3.765×10^{-4}	Wratten <i>et al.</i> (1979)
G.S. \geq 60 - <70	4.87×10^{-4}	Lee <i>et al.</i> (1981)
G.S. \geq 70 - <77	3.83×10^{-4}	Holt <i>et al.</i> (1984)
G.S. \geq 77 - <83	1.92×10^{-4}	
\geq G.S. 83	0.0	Assumption

Estimated daily yield loss (L_i) was dependent on the daily aphid index (A_i , the sum of the numbers of aphid units) present on plants:

$$L_i = A_i R_i \quad (10)$$

and then accumulated to give a total yield loss (T_i):

$$T_i = \sum A_i R_i \quad (11)$$

Field data for validation

The model was validated using data from field trials at Rothamsted, southern England, in 1979, 1985 and 1986.

In 1979, four counts of aphid densities made of the total, nymphal stage, and alate and apterous adult populations during the summer were from a multidisciplinary field experiment (Prew *et al.*, 1983). They were from plots not receiving summer aphicide and separated into early and late sowing treatments and were used in the validation of the model.

In 1985 and 1986, the total aphid densities sampled at approximately weekly intervals in the field were from eight and 12 unsprayed plots, respectively, in experiments to study insecticide persistence on aphids (Carter *et al.*, in press).

Aphid migration data were from the 12.2-m suction trap and maximum and minimum temperatures from the meteorological station, both at Rothamsted.

The model was started on the day the first *M. dirhodum* was sampled in the suction trap. The corresponding initial crop growth stages were G.S. 31 in 1979, 35 in 1985 and 68 in 1986. The number of shoots per square metre was set at 500 each year.

Results

In 1979, the model predicted accurately the size of the observed maximum aphid density and the timing of its occurrence (109 aphids/shoot on 24 July). The model also predicted accurately the exponential increase of *M. dirhodum* after 25 June (Fig. 3 A & B). Early in the season, the model slightly overestimated the field populations in both the early and late sown plots, but the predictions were more accurate later in the season.

In 1985, the predicted population was larger and occurred seven days later than the observed peak. The observed aphid population increased steadily until 15 July and then declined rapidly. The model overestimated the population starting on 24 June and carried on increasing until 22 July to reach a peak of 59.9 aphids/shoot (Fig. 3C).

In 1986, the model again overestimated the peak density but was only three days late in predicting its timing (6.3/shoot on 17 July). It was late estimating the initial build-up (Fig. 3D).

The simulation results from the total population were separated into three components: total nymphs, and alate and apterous adults in 1979 (Fig. 4). The model accurately predicted the total numbers of nymphs and apterous adults (Fig. 4A & C) but underestimated the observed peak of alates (Fig. 4B).

The model predicted a final yield loss of 11.5% compared with the observed yield loss of 12.7% in 1979 (Prew *et al.*, 1983) and also accurately predicted an average yield loss of 5.5% while the yield loss was 4.7% in the experimental plots in 1985. The estimated and field yield losses were both near zero in 1986.

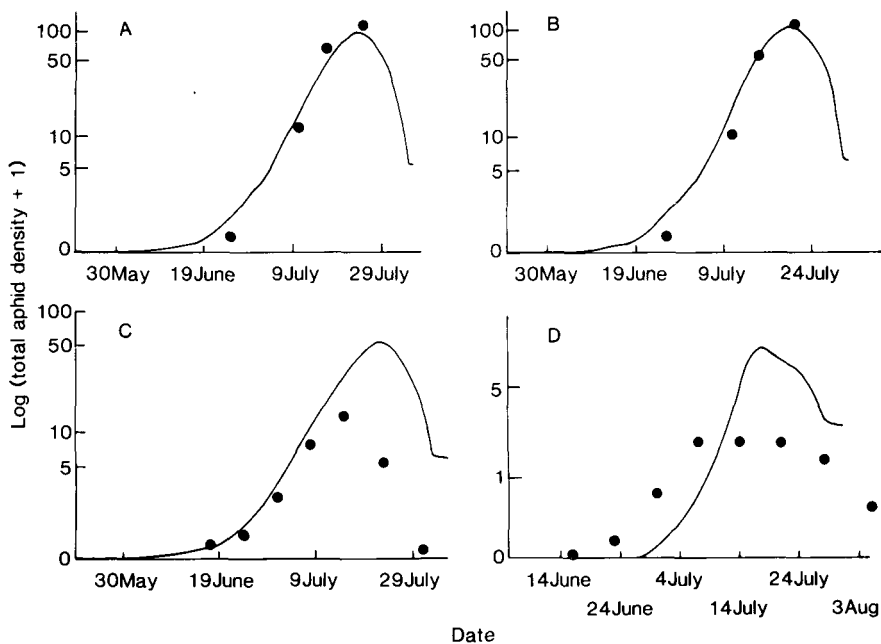


Fig. 3.—Comparison of predicted (—) and observed (●) total densities of *Metopolophium dirhodum* in (A) early and (B) late sown plots in 1979, (C) 1985 and (D) 1986.

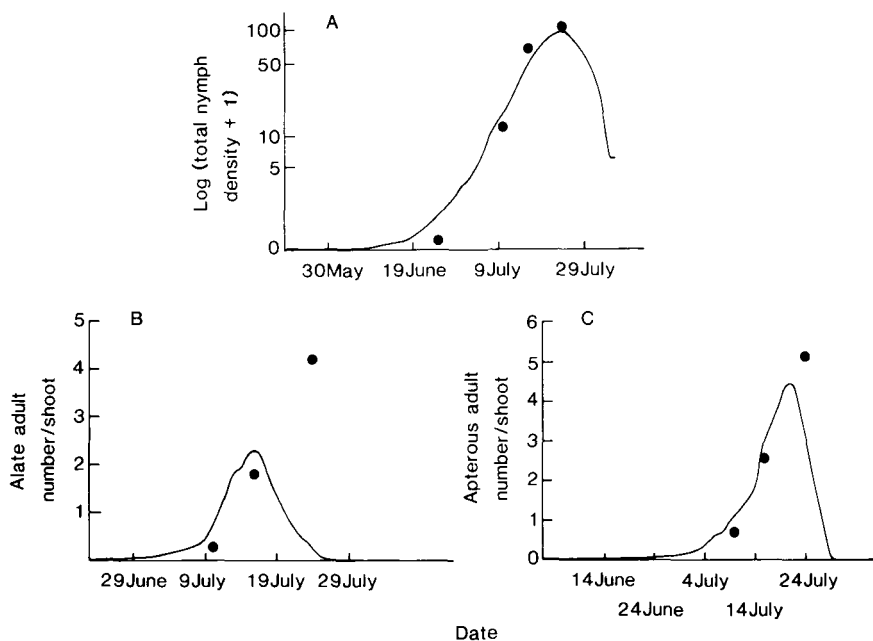


Fig. 4.—Comparison of predicted (—) and observed (●) densities of (A) nymphs, (B) alate adults and (C) apterous adults of *Metopolophium dirhodum* from early sown plots in 1979.

Discussion

In 1979, there were few immigrants and small field populations in spring, but the warm dry weather in July and delayed crop development due to cold weather in the previous winter allowed these populations to increase rapidly to very high levels in the absence of significant effects of natural enemies (Dewar *et al.*, 1980). The model predicted accurately this exponential increase. In contrast, in 1985, cool and wet weather in June prevented rapid aphid increase early in the season and when the aphid population did start to increase, the cereals had developed beyond the more susceptible stages (Tatchell *et al.*, 1986). Therefore, the aphid populations remained small and were well below the levels of infestation predicted by the model (Fig. 3C). In 1986, the first *M. dirhodum* was caught at the end of June at Rothamsted and natural enemies may have had a significant effect on reducing aphid population development (Carter, 1987). The model only included a low background mortality so these effects of natural enemies could explain the gradual divergence of predictions from the model with the observed densities and also the earlier decrease in the observed population (Fig. 3C & D).

The numbers of immigrant aphids were obtained from daily suction-trap samples, and these may be less reliable at low densities than at high ones. For example, aphids occurred in the field about ten days before the first *M. dirhodum* was caught in the suction trap in 1986. Also, the proportions of the suction-trap samples during the season, which were assumed to be immigrants based on the Equation 2 in the model, may not accurately reflect the proportions in the population sampled.

The predicted yield losses were similar to those in the field in the three years, although the predicted yield loss was slightly higher in 1985. However, the observed yield losses were obtained from the differences between control plots and plots sprayed with insecticide. The yield in the latter would still be lower due to the presence of the reduced aphid populations so that the actual yield losses would have been slightly higher than the observed results.

Acknowledgement

The work is supported by the British Council and the Chinese Government.

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(Received 25 October 1988)

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