TEMPERATURE-DEPENDENT PHENOLOGY OF GORSE SPIDER MITE

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SUMMARY

The gorse spider mite (*Tetranychus lintearius* Dufour) was introduced into New Zealand in 1989 as a biological control agent for gorse. We present experimental results for the relationships between mite development rates and temperature, and preliminary results from a phenological model for the mite, as a precursor to a full population model. Simulated egg hatching times of gorse spider mites, using both linear and power functions for egg development rate were compared with real data on potted gorse plants, and sensitivity analysis was carried out.

Keywords: biological control, gorse spider mite, phenological model, development rate

INTRODUCTION

The gorse spider mite (*Tetranychus lintearius* Dufour) was introduced into New Zealand in 1989 as a biological control agent for gorse (*Ulex europaeus* L.) (Hill *et al.* 1989). Although now widely distributed throughout many areas of New Zealand, establishment of the mite in the north of the North Island and on the West Coast of the South Island has been difficult. Since the first release of a strain from Cornwall in England, five new strains from Portugal and Spain have been released, one of which has established successfully near Auckland and on the West Coast (Hill *et al.* 1993). Suggested reasons for the difficulties in establishing the mite include predation pressure by *Stethorus* sp. or *Phytoseiulus persimilis* (Hill *et al.* 1991; Peterson 1993) and climatic factors, since the areas where establishment has been least successful have wet, mild winters (Hill *et al.* 1991). Both field (Hill 1993) and laboratory (Millar 1993) research has shown that rainfall reduces the capacity of gorse spider mite populations to increase, but the effect of temperature has not been ascertained.

In this paper, we describe experiments to determine the relationships between mite development rates and temperature, and initial results from a phenological model designed to predict mite development in the field. This represents the first step in the development of a full temperature-driven population model of the mite, which will increase understanding of its population dynamics and differential establishment in different climatic regions.

METHODS

Development rate / temperature experiments

Development periods of the mite life stages were determined in constant temperature cabinets set at 10, 13, 15, 18, 20, 25 and 27° C. Relative humidity in the cabinets was 40% and photoperiod was 16:8, L:D. Determination of the egg development period was later repeated at 27° C and 23° C. For each temperature, 50 laboratory-reared adult females were placed on each of three gorse shoots. After 8 h the adult mites were removed and any eggs laid were counted. Between 42 and 223 eggs were laid at each temperature. Gorse spines were either examined daily (<20° C) or twice daily (>20° C) under a binocular microscope (x 50) to determine the time of egg hatch. A sub-sample of 30 larvae was then taken at each temperature, and each individual was

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placed on a gorse stem, trimmed to one spine. Development was followed through to the adult stage and recorded separately for eggs, larvae, protonymphs and deutonymphs. Development rate was determined as the reciprocal of development period in days. Two simple and appropriate models for temperature-dependent development rates (linear and power) were fitted to the data by least squares regression of suitably transformed data. Statistical analyses were carried out using Microsoft Excel (version 4.0). The 'best fit' function chosen for each stage was the one with the highest R^2 value, and after examination of residual plots. To simulate variation in development rates in a phenological model (Logan and Amman 1986), and hence the spread in emergence of individuals from one life stage to the next, the coefficient of variation (standard deviation divided by the mean) was determined for each life stage at each temperature. A mean coefficient of variation over all temperatures was used for each development stage.

Phenological model

The structure of a deterministic mite population model (Hayes 1989) was used as the framework of the gorse spider mite phenology model. The model updates development iteratively over discrete time intervals, during which temperatures are assumed to be constant. In this case hourly temperature data are used. For convenience, the mite life cycle was divided into seven different stages; eggs, larvae, protonymphs, deutonymphs, pre-oviposition females, oviposition females and males. To simplify model development, the quiescent period following each juvenile stage was included with the appropriate active stage of mite development. An initial check of the model's phenology prediction under a variable temperature regime, was carried out at Lincoln between March and May, 1994. Twenty adult female gorse spider mites were placed on each of five potted gorse plants, trimmed to a single shoot and kept in the laboratory at a mean temperature of 20° C. After 24 h, adult mites were removed and the number of eggs on each shoot was counted under a binocular microscope (x 50). The plants were placed outside in a sunny, semi-sheltered site and examined at 3 - 6 day intervals to determine the mite stage present and any mortality. Temperature was measured continuously with a Campbell CR10 data logger housed in a Stevenson screen. Five temperature probes protected from direct sunlight measured the temperature of each plant, and one probe measured air temperature inside the Stevenson screen (for later correlative prediction of gorse plant temperatures from weather station data). Mean hourly temperatures were recorded, and the average hourly temperature from the five plants was used as input to the model. Two simulations, one using the linear and one using the power function for egg development rate, were generated for 25 days starting with 100% eggs and zero accumulated development.

Sensitivity analyses of simulated egg development for both models were carried out by changing the hourly temperature inputs by $\pm 1^\circ \text{C}$ and the development rates by $\pm 10\%$.

RESULTS

Development rate / temperature experiments

Gorse spider mite eggs hatched at all temperatures except 10° C where there was 99% mortality. At 13° C egg hatch was close to 100%, but all individuals died as larvae. At temperatures higher than 13° C, development to adults was completed. For all developmental stages, there was a monotonic increase in development rate with increasing temperature within the range of temperatures studied (Fig 1.). For protonymphs and deutonymphs the power function was the best fit; for eggs and larvae both linear and power functions fitted the data equally well with insignificant differences in R^2 values (Table 1). These two functions differ at the temperature extremes and when extrapolated beyond the data. Implicit in a linear relationship is a low temperature threshold for development (where the linear function intersects the x axis), whereas the power curve predicts that development rate decreases to zero as the temperature approaches zero. At high temperatures, the power curve may predict higher development rates than the linear function, fitted to the same data.

Figure 1: Temperature-dependent development of *T. lintearius* eggs, larvae, protonymphs and deutonymphs, showing the mean $\pm$ 95% confidence interval and the 'best fit' development rate model for each stage.

TABLE 1: Comparison of different functions fitted to temperature-dependent development rate data for *Tetranychus lintearius* developmental stages. R=development rate (proportion / day), T = temperature °C.

Model	Function fitted	R ²	n
Eggs			
linear	$R = 0.01399T - 0.16307$	0.964	720
power	$R = 4.1368 \times 10^{-5} \cdot T^{2.6199}$	0.967	720
Larvae			
linear	$R = 0.02438T - 0.2753$	0.89	127
power	$R = 1.724 \times 10^{-4} \cdot T^{2.3518}$	0.88	127
Protonymphs			
linear	$R = 0.025T - 0.2689$	0.82	117
power	$R = 3.238 \times 10^{-4} \cdot T^{2.175}$	0.85	117
Deutonymphs			
linear	$R = 0.02424T - 0.2799$	0.86	107
power	$R = 1.886 \times 10^{-4} \cdot T^{2.312}$	0.90	107

Figure 2: Comparison of simulated and actual *T. lintearius* egg hatch at ambient temperatures, using two different egg development rate models.

Prediction of egg development under fluctuating temperatures

Field evaluation of the development of gorse spider mite was more difficult than anticipated. Despite placement of sticky traps below the potted gorse plants, large numbers of active mites were lost, or could not be found during examination. It is likely that many mites either died or were blown off the plants. After starting with 156 eggs, a maximum of 23 active mites on all five plants were found post-hatching and the data were considered unreliable for validation of total development. However, the time of 50% egg hatch was reliably determined and provided a useful check on the model's ability to predict egg development under fluctuating temperatures. Simulated 50% egg hatch predicted by the linear function was approximately 4 days later than real events and using the power function only 1 day later (Fig. 2). The average temperature on the plants was approximately 14°C, with temperatures fluctuating mostly between 8 and 20°C, representing the lower part of the egg development rate curve.

The results of the sensitivity analysis for the two different models are shown in the Table 2.

TABLE 2: Sensitivity of model predictions of the date of 50% egg hatch using the linear function and the power curve for egg development rate. Figures in brackets are the difference in days from the appropriate reference model prediction.

Factor changed	Model using power curve	Model using linear function
Reference model	16 April	19 April
Temperature + 1°C	13 April (-3)	15 April (-4)
Temperature -1°C	19 April (+3)	29 April (+10)
Development rate +10%	14 April (-2)	17 April (-2)
Development rate-10%	18 April (+2)	24 April (+5)

DISCUSSION

In this initial validation, the model using the power curve for egg development rate was a good predictor of the time of 50% egg hatch, but the linear model performed less well. The difference is due both to the closer fit of the power curve to development rate at 13°C, and the differences between the two functions when extrapolated beyond the data into the low temperature region. Linear models are widely used for phenology prediction but in this particular case, the power curve appears to be superior.

In the sensitivity analysis, both models were more sensitive to a 1° C change in temperature than to a 10% change in development rate. Accurate determination of temperature during laboratory experiments and when using the model predictively is clearly important. Given the differences in temperatures between some of the regions where the mite has been slow to establish, and the field site in Canterbury, we could expect differences in population dynamics in these regions. In particular, mild autumn temperatures would be expected to maintain gorse spider mite development longer than in the cooler Canterbury temperature regime.

Noticeably, the two models' sensitivity to temperature differed quite markedly. The extreme sensitivity of the linear model to a small temperature decrease is due to the implicit temperature threshold for development, and because temperatures in the validation study fluctuated precisely around this threshold. The threshold is itself determined by extrapolation and the extreme sensitivity to temperature could be an artifact. There may be a real temperature threshold for development but it is likely that low temperature-induced mortality will override the importance of zero development rate in the low temperature region. Temperature related mite survival could be an important component of differential success of gorse spider mite in different climatic regions and is the next important component of mite population dynamics to be incorporated into the model. Modelling temperature-dependent mortality has received much less attention in the international literature than has modelling of temperature-dependent development, yet in cases like the gorse spider mite it may be of even greater significance at the population level.

A different system is needed for validating immature development periods and further validation of all stage development should be carried out in different variable temperature regimes. Validation at the low temperature extreme is particularly important as this is the likely temperature range contributing to differences in population dynamics of the mite in different regions of New Zealand, and is the range over which the extrapolated development rate/temperature relationships fitted to the same data differ most.

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