~~Application of the process simulation technique in biological~~
control of the fruit tree red spider mite, Panonychus ulmi (Koch).

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Introduction

Several insect and mite species are potential pests of fruit trees. A very important pest is the fruit-tree red spider mite, Panonychus ulmi (Koch), almost unknown as a pest before World War II. It became important with the chemical control of apple scab, powdery apple mildew, and of insects and the introduction of nitrogen fertilizers. Probably predators were important before that time, but they were annihilated by these cultural methods, leaving the spider mites unharmed. The evidence for this hypothesis is critically reviewed by Huffaker, McMurtry and Van de Vrie (1970). The fruit tree red spider mites readily develop resistance against acaricides, and be it for this reason only, biological control is urgently needed.

Nowadays attempts for biological control are for the greater part based on trial and error; introduction of parasites and predators, often from abroad, is done untill some success is achieved and control of the pest population is attained. Speculative explanations of regulation may be given afterwards; verification experiments often are omitted. This trial and error approach, although being very much time consuming procedure, merely based on the experience of the biologist or agriculturist, has provided many successful cases of biological control.

Experiments with releasing natural enemies, as predatory bugs, beetles, and mites have shown that control of the fruit tree red spider mite is most successfully achieved with predatory mites, when at least the spray program is modified: Control is not considered here as the complete eradication of the pest organism, but as the regulation of its population density below the economic damage levels.

Development of simulation models

The aim of this work is the construction of bridges between the biological control with predacious mites in the field and the analytical method of

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quantities which the model produces for the user. They may be state variables, rates, and auxiliary variables.

After calculating the rate, the state variables are updated by adding these rates multiplied by a small time interval, which is no short that the rates may be assumed to be constant.

Simulation of population development

The simulation of the development of populations of mites plays a central rôle in this study, and therefore its main aspects are explained with the aid of an example. In the relational diagram of fig. 1 the process of hatching is given. The amount of eggs and the amount of larvae, two state variables, are presented within rectangles. They are connected by a full drawn arrow that designates the flow of individuals from one state to the other. This flow is regulated by the hatching rate, a variable within the valve symbol, dependent on a rate constant, the relative hatching rate (RHR), and on the amount of eggs, both dependencies being presented by dotted lines.

In CSMP (Continous System Modelling Program), the two state variables are presented by integrals,

EGGS = INTGRL (100.,-HR)
LARV = INTGRL (0., HR)

The first number in the argument is the initial value, which is in this case zero for the number of larvae and arbitrarily assumed 100 for the number of eggs. The second variable in the argument is the rate of change, the hatching rate, which decreases the number of eggs and increases the number of larvae. This hatching rate may be equal to:

HR = RHR x EGGS

in which the relative hatching rate is defined as a parameter at for instance, 0.1 day^{-1} with:

PARAMETER RHR = .1

Obvious, there is an exponential decrease in the number of eggs and a corresponding increase in the number of larvae. Of course, the hatching rate of eggs may be considered as a function of temperature. A Birth Rate of eggs may be added , and a Death Rate of eggs may also be taken into account. This changes the first integral to:

EGGS = INTGRL (100., BR - DR - HR)

and the hatching rate in:

HR = EGGS x AFGEN (RHRT,TEMP).

This AFGEN function makes linear interpolation between the found values for RHR possible (Arbitrary Function GENerator). The other rates, Birth Rate and Death Rate should of course also be quantified.

The average residence time in the egg stage is the inverse of the relative hatching rate, i.e. 10 days in this case. Hence, the duration of the process is controlled by the relative hatching rate and in this respect the simple program satisfies the need.

However, the shape of the hatching curve is still a problem. Actual experiments reveal that after the onset of the hatching process, during some days small numbers of larvae appear. Then the hatching rate increases and decreases again. The complexity of the hatching process and the many subprocesses concerned, obviously cause this Gaussian hatching curve. Without analyzing these underlying processes in detail, they may be mimicked by more sophisticated simulation programs. The processes depending on temperature and other abiotic factors are programmed in such a way that temperature and other abiotic factors dependent standard deviations are incorporated. This way of modelling is presented by De Wit and Goudriaan (1974) and in the description of the presented model by Rabbinge (in prep.). This method of modelling complex processes in such a way that their dependency on abiotic factors and the stochasticy of the processes is mimicked in a correct way, forms the core of the simulation programs described here and is used to describe the development of the various stages of the prey and the predacious mites.

The construction of relational diagrams

In the relational diagram (fig. 2) the life cycle of P. ulmi is given: the adult female (AFS) produces eggs (Es) at a certain oviposition rate (Fs). The oviposition rate depends on the number of females and the relative oviposition rate per female. This relative oviposition rate depends on the temperature and also on the relative air humidity when this is below 60% or above 90%. The eggs hatch with a certain rate, the hatching rate (number per unit of time) which depends on the number of eggs and the relative hatching rate as described before. The rectangles represent more than one integral, but for reasons of convenience not all of them are represented in the relational diagram. However, not all eggs hatch; the mortality rate (MEs) depends on the number of eggs and the relative rate of mortality. These parameters are dependent on temperature and relative air humidity.

The larvae develop into protochrysalids with a developmental rate depending on the number of larvae and the relative development rate. Here the same procedure is executed, i.e. part of the larvae become protochrysalids and another part dies. The protochrysalids develop into protonymphs and these become deutochrysalids. From the latter, deutonymphs arise; in this stage the sensitive period for the induction of diapause by daylength and food is located. The combination of these factors determines the proportion of females producing overwintering eggs, (Lees, 1953).

In the relational diagram of fig. 2, the full drawn arrow gives the flow of individuals to the "winter" and "summer" form. These females appear from the teleiochrysalids, the third quiescent stage. Sex ratio is constant at the population densities we are taking in consideration. The adult female is thought to be always fertilized and to start ovipositing after a praeoviposition period which depends to a large extent on the temperature. The oviposition rate, the life span and the mortality in the adult stage are dependent on abiotic conditions and the quality and quantity of the food.

In the whole relational diagram mortality rates are not only influenced by abiotic factors, but also by predators. Only predacious mites are taken into consideration, and this means an effect on the mortality of the larvae, protonymphs, deutonymphs and adults as is given by the dotted line in the relational diagram. The predation process is given as an abbreviation (PRED). This subprogram is influenced by the number of prey and by the number and state of the predators. In the relational diagram of fig. 3 the population development of the predators is given in the same way as was done for the prey. The overwintering female becomes active in spring when certain abiotic conditions are fullfilled and starts egg laying when sufficient food (spider mites, pollen, honeydew) is available. Adult females, deutonymphs and protonymphs are active in the predation process as is shown by the dotted line to PRED in the relational diagram.

Verification experiments

The population model is run with time steps of 0.1 day and gives the results that have to be verified in a series of independent experiments. The time step of 0.1 day depends on the time constant of the system to be simulated. Quantification of the different rates is achieved by process experiments; relative development rates, relative mortality rates, predation rates and oviposition rates are measured in dependence of the abiotic conditions in laboratory experiments. The influence of the host plant is quantified in waterculture experiments and verified in field experiments with different nitrogen levels and osmotic values of the nutrient solution.

Micro- meso- and macroexperiments in which the population fluctuations are followed in small ecosystems under controlled conditions, on small apple rootstocks in the greenhouse under controlled conditions and in the orchard under measured conditions, are the verification of the simulated model. In figure 4 a provisionally simulated curve and a confidence interval are given from the data obtained in the greenhouse.

The value of the model depends on the accuracy of the resemblance to the results of the verification experiments. A sensitivity analysis with the simulation model will show the importance of the different input variables and provides the basis for a simple descriptive model. The explanatory value of this model is limited but it describes the considered phenomena well and is therefore usable as a management tool in biological control of the fruit tree red spider mite.

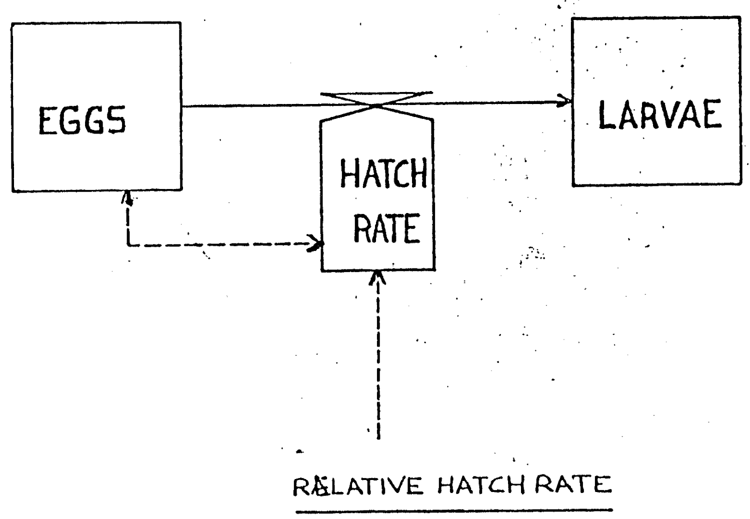
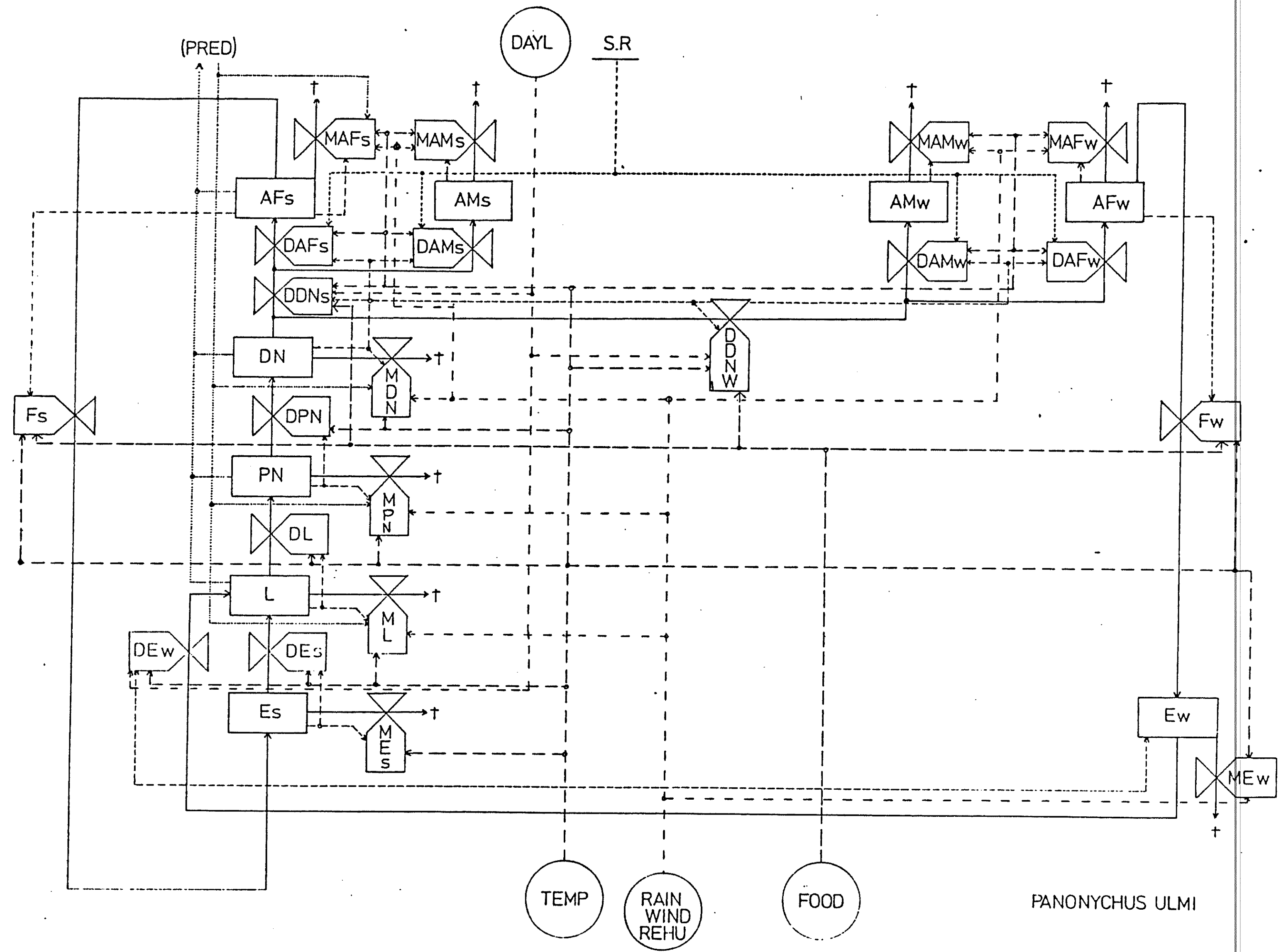
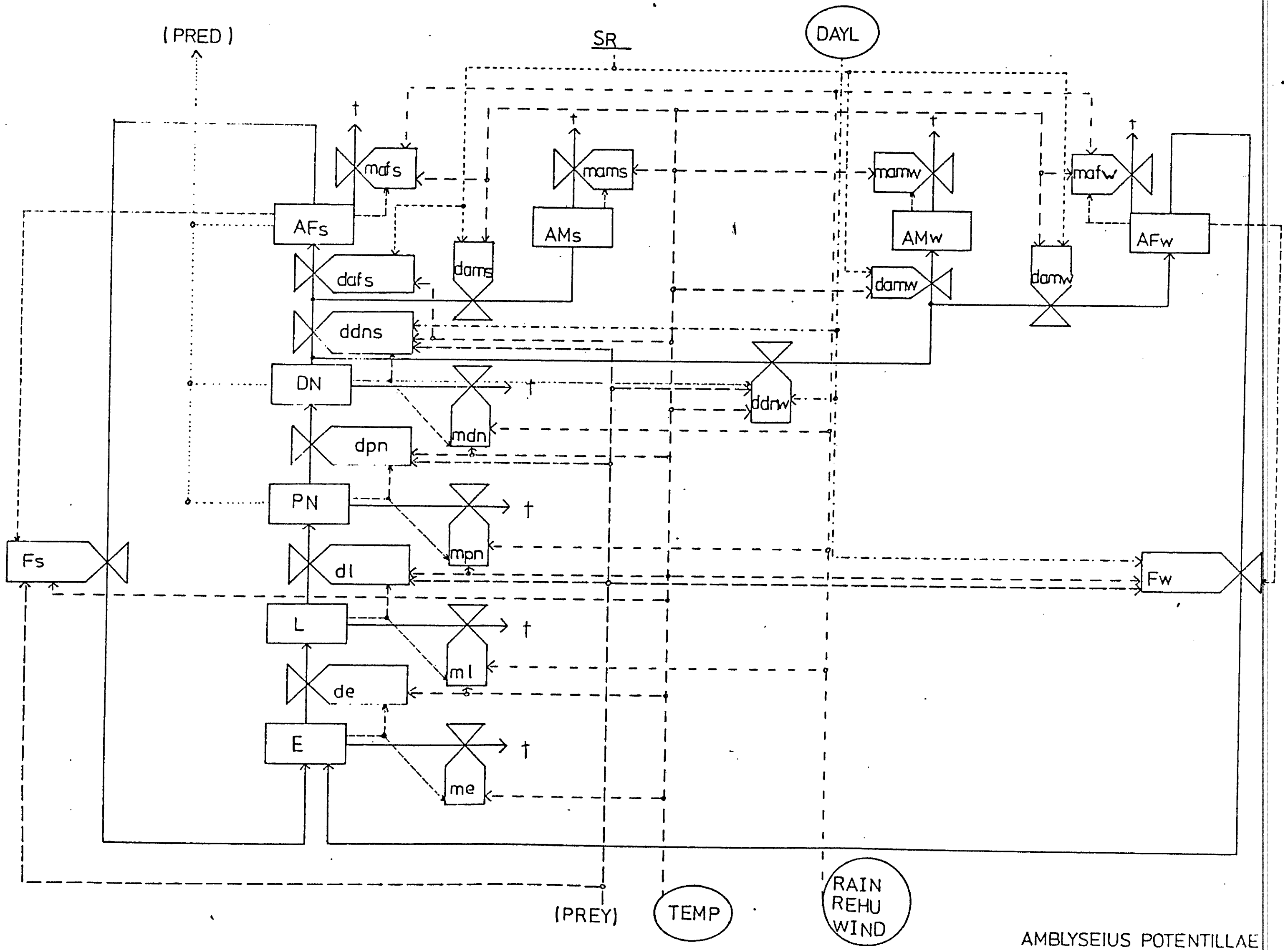


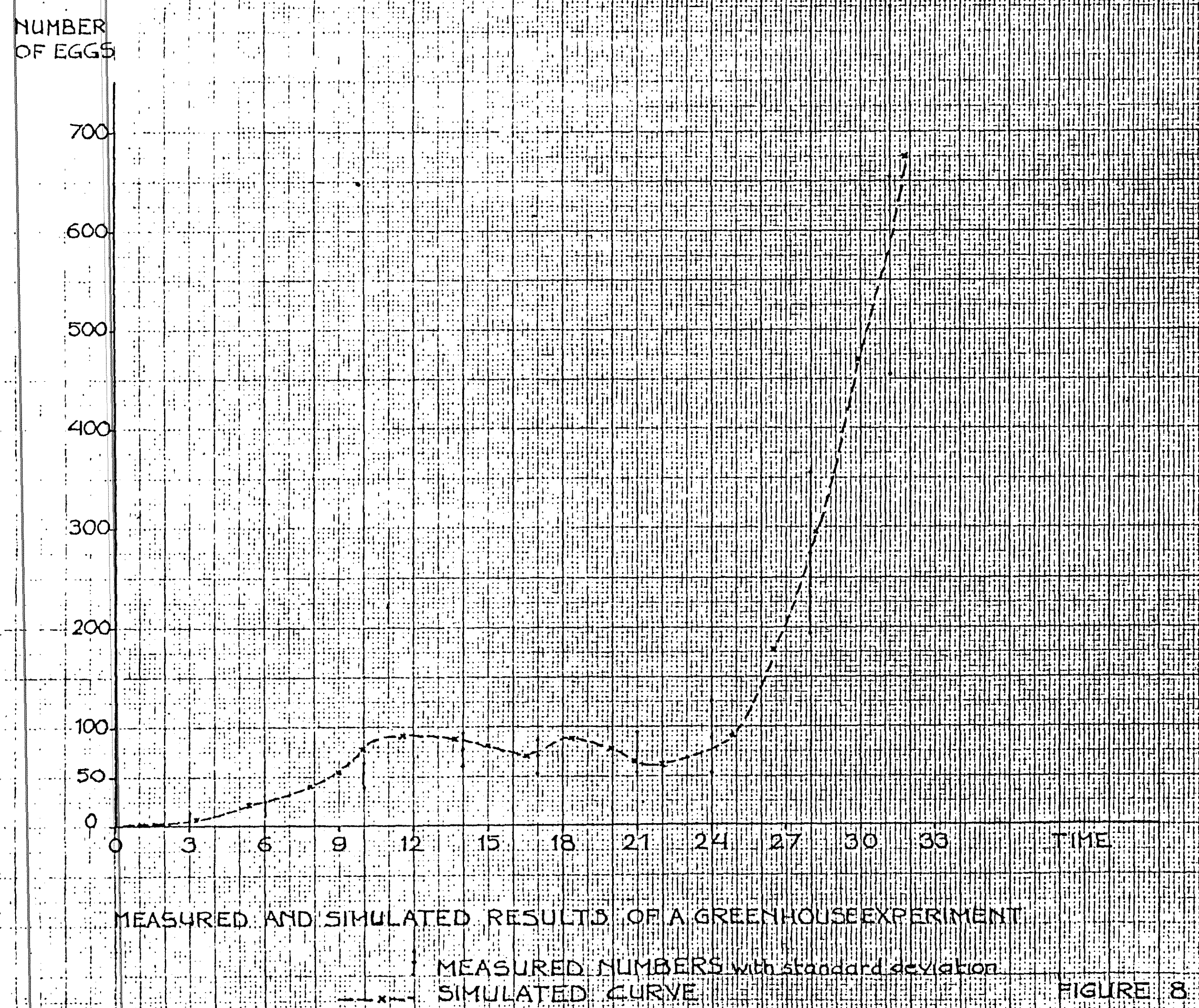
FIGURE 1.



PANONYCHUS ULMI

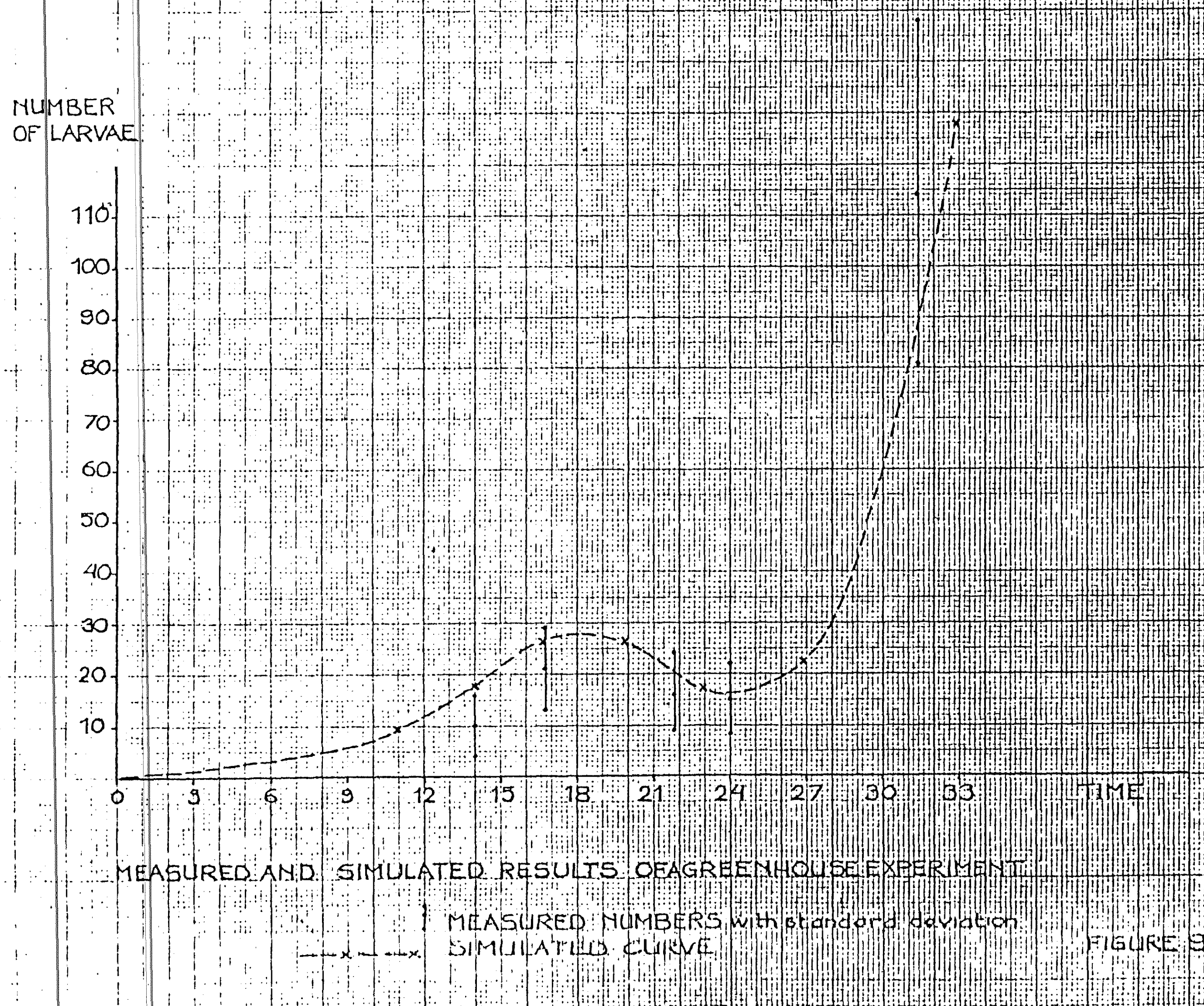


AMBLYSEIUS POTENTILLAE



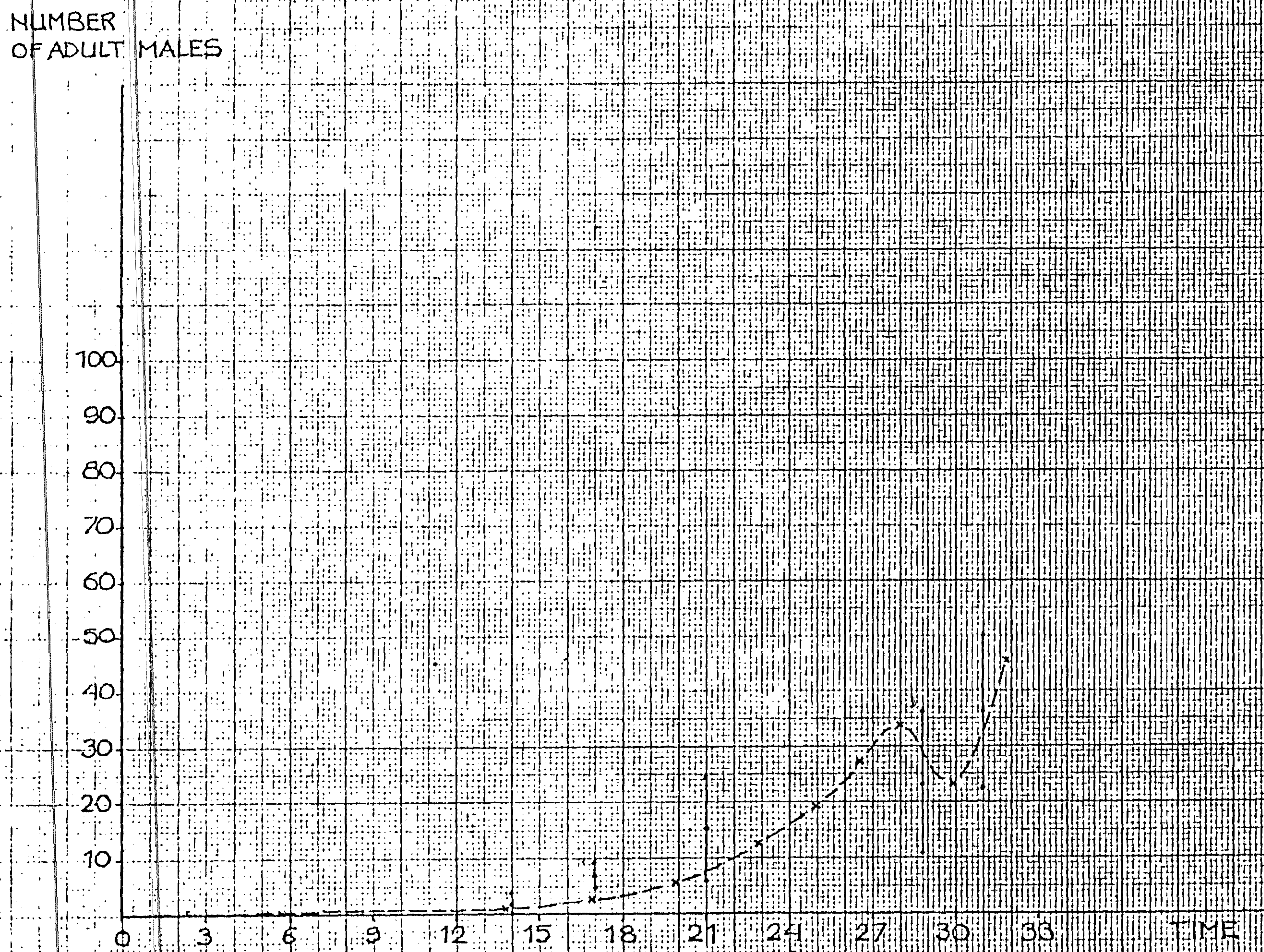
MEASURED AND SIMULATED RESULTS OF A GREENHOUSEEXPERIMENT

FIGURE 8



MEASURED AND SIMULATED RESULTS OF A GREENHOUSE EXPERIMENT

FIGURE 9



MEASURED AND SIMULATED RESULTS OF A GREENHOUSE EXPERIMENT

MEASURED NUMBERS with standard deviation
SIMULATED CURVE

FIGURE 10