ECOTOXICOLOGY AND ENVIRONMENTAL SAFETY **33,** 207–216 (1996)
ARTICLE NO. 0027

Effect of Dimethoate on Body Growth of Representatives of the Soil Living Mesofauna

PERNILLE FOLKER-HANSEN, PAUL HENNING KROGH,[1] AND MARTIN HOLMSTRUP

Ministry of the Environment, National Environmental Research Institute, P.O. Box 314, Vejlsøvej 25, DK-8600 Silkeborg, Denmark

Received December 27, 1994

For the elucidation of effects of a pesticide on life-cycle parameters of arthropods, applicable in the development of ecotoxicological test procedures with soil living animals, attention was drawn to body growth, which has previously been described as a sensitive parameter in Collembola. Body growth of the following three soil-dwelling arthropods was studied under the influence of dimethoate: *Folsomia fimetaria* (L.), *Hypogastrura assimilis* Krausbauer, and *Hypoaspis aculeifer* Canestrini. The effect of this insecticide and acaricide proved to be sex and species specific. Two models were compared for modeling individual body length. The logistic growth model fitted data for all species, whereas the growth model of von Bertalanffy was less applicable for *F. fimetaria* and *H. aculeifer.* The growth rate coefficient of the logistic model proved to be a robust parameter useful for predicting effects of dimethoate on juvenile growth of *F. fimetaria* and *H. aculeifer.* Adverse effect concentrations on growth for these species were the following: EC_{10} = 0.11 mg dimethoate/kg dry soil for *F. fimetaria* and EC_{10} = 0.59 mg dimethoate/kg dry soil for *H. aculeifer.* For *H. assimilis,* no adverse effects on growth were observed at the tested concentrations. The results are compared to other life-cycle parameters (endpoints).

INTRODUCTION

In terrestrial ecotoxicology, much effort is at present allocated to studies of sublethal effects of chemical substances on soil-living arthropods. This is due to the recognition of the beneficial role of these animals and to the demand for standardized tests with arthropods for evaluation of ecotoxicological properties of new and existing chemicals (Løkke and van Gestel, 1993). Different chemicals seem to affect life-cycle parameters of various arthropods differently (van Straalen *et al.*, 1989; Crommentuijn *et al.,* 1993). Survival and reproduction are parameters most directly related to the population level (Leon and van Gestel, 1994). For reproduction strategists, reproductive rate is undoubtedly the most important factor as suggested by van Straalen *et al.* (1994). Other life-cycle parameters, e.g., growth, however, might be more sensitive and therefore more useful to provide an early warning, as suggested by Crommentuijn *et al.* (1993). Growth also has the advantage of being a steady parameter, primarily influenced by temperature, and is supposed to be less prone to variation compared to reproduction for example (von Bertalanffy, 1960).

Growth of soil-living fauna under the influence of environmental or physiological disturbance has been studied in many representatives of larger functional groups, i.e., micro-, meso-, and macrofauna (Hubbell, 1971; Petersen, 1971; Schiemer, 1982; Bengtsson *et al.,* 1983; Badejo and van Straalen, 1992; Springett and Gray, 1992; Crommentuijn *et al.,* 1993). For the mesofauna group, the Collembola has probably received the most attention (Petersen, 1971; Bengtsson *et al.*, 1983; Badejo and van Straalen, 1992; Crommentuijn *et al.*, 1993; Tranvik *et al.*, 1993), whereas others, e.g., predatory mites (Mesostigmata), have received less attention.

Studies of chemical effects on growth of Collembola have been focused on heavy metals (e.g., Bengtsson *et al.*, 1983; Tranvik *et al.,* 1993; Crommentuijn *et al.*, 1993) and to a limited extent on pesticides (Badejo and van Straalen, 1992). Measurements of growth that have been used are number of exuvia and weight of individuals at the beginning and the end of the experiment (van Straalen *et al.*, 1989; Badejo and van Straalen, 1992). Growth rate recorded by measurement of juvenile body length, though, has proved to be a more sensitive parameter to toxic effects (Tranvik *et al.*, 1993).

By adopting this approach, the aim of the present work was to investigate the effects of the pesticide dimethoate on individual growth of representatives of the mesofauna and to relate the effects to other parameters relevant to the fitness of the species concerned. Furthermore, the endpoints extractable from the parameter ''growth'' (length and parameters of growth models) were discussed.

Juveniles of the following two springtails and a predatory mite were exposed to a range of dimethoate concentrations selected with respect to recommended field dosages: *Folsomia fimetaria* L. (Collembola; Isotomidae), *Hypogastrura assimilis* Krausbauer (Collembola: Poduridae), and *Hypoaspis aculeifer* Canestrini (Gamasida: Laelapidae), subgenus *Geolaelaps sensu* Walter and Oliver (1989). Body length

[1] To whom correspondence should be addressed.

0147-6513/96 $18.00

was measured two times weekly and asexual egg production was recorded in *H. aculeifer.*

MATERIALS AND METHODS

Animals and Stock Culture

The three microarthropod species all originate from Danish agricultural soil, where they are common inhabitants. *Folsomia fimetaria* is a hemiedaphic, nonpigmented, eyeless species that reproduces sexually. It is not readily disturbed and therefore easy to handle. *Hypogastrura assimilis* also reproduces sexually, but differs from the aforementioned species by being epi- to hemiedaphic and pigmented, as well as having eyespots. Compared to *F. fimetaria,* this species is more difficult to handle as it doubles up when disturbed and is more likely to jump. *Hypoaspis aculeifer* has an arrhenotokous mode of reproduction (De Jong *et al.,* 1981), i.e., only male offspring are produced from unfertilized females. The species is characterized as being polyphagous and having a hemiedaphic/euedaphic distribution (Sardar and Murphy, 1987). The three species have been cultured in this laboratory for the past 3 years and breed continuously on a moistened substrate of plaster of paris/charcoal prepared according to Usher and Stoneman (1977). The Collembola were fed dried baker's yeast [*Saccharomyces cerevisae* Meyen ex. Hansen (Ascomycotina: Saccharomycetaceae)], and the predatory mite culture was fed Collembola (*F. fimetaria* or *Folsomia candida* Willem).

Chemical

Dimethoate *O,O*-dimethyl *S*-methylcarbamoylmethyl phosphorodithioate (IUPAC) is a broad-spectrum insecticide and acaricide that is used as a contact and systemically acting pesticide (Anonymous, 1989). Dimethoate acts as a cholinesterase inhibitor. Dimethoate is mainly degraded hydrolytically, photochemically in moist air, and enzymatically in plants ($t_{1/2}$, 2–9 days) (El Beit *et al.,* 1977, 1978; Kolbe *et al.,* 1991). Persistence and bioactivity in soil is variable and dependent on pH, organic material, clay, humidity, temperature, and microbial biomass for example (El Beit *et al.,* 1977, 1978; Kolbe *et al.,* 1991; Joy and Chakravorty, 1991).

The dose recommended for controlling aphids in cereals in Danish agriculture is ~320 g/ha (Kristensen *et al.,* 1993). If assuming an even distribution in the top 5 cm or 2.5 cm soil, and a soil density of 1.44 kg/dm^3, the concentration of dimethoate in dry soil is 0.44 and 0.89 mg/kg, respectively.

Monitoring Equipment

To make a record of the individual increase in length over a period of 30–40 days, with as little disturbance as possible, digital image processing equipment (DIP) was used. DIP consisted of a stereo microscope mounted with a video camera and connected to a monitor and a computer: pictures of living specimens could be fixed and displayed on the monitor and measurements made manually with a computer mouse.

Soil Preparation and Application Procedures

Animals were exposed to dimethoate via the soil. Soil preparation and pesticide application were performed as follows. A typical Danish agricultural sandy loam from Kalø, Jutland (1.6% total org. C, 1.7% humus, 10.6% clay, 14.5% silt, 45.8% sand, 26.4% coarse sand, pH_{H_2O} 7) was defaunated [alternately dried (60°C), frozen (−35°C), and incubated at 20°C in wetted condition], sieved (2-mm mesh net), and finally stored at −18°C. Inoculum (a soil–water suspension containing microorganisms) was prepared by making a suspension of fresh Kalø soil, leaving it for 24 hr at 20°C, and subsequently sieving it through a 50-μm mesh net.

Dimethoate concentration series were prepared by diluting the stock solution (402 mg active ingredient/liter) with the inoculum. The concentration series were subsequently mixed with the dried, defaunated soil, 4 ml solution per 26 grams soil, giving a water content of 15.4% (approx 50% maximum water-holding capacity). To the control, only the inoculum was added. The treated soil was left in open beakers in a fume cupboard for 16 hr for evaporation of additives present in the dimethoate stock solution. After adjustment of the evaporation losses with deionized water, the content of the beakers was finally mixed thoroughly, covered with foil, and left for a short period before use. The different species were exposed to the following dimethoate concentration series given as mg/kg soil (dry weight): *F. fimetaria* and *H. assimilis*, 0, 0.029, 0.051, 0.093, 0.167, 0.3; *H. aculeifer*, 0, 0.230, 0.333, 0.483, 0.7.

Containers and Transfer of Animals

Multidishes (Nunclon, NUNC), with 24 circular holes (diameter = 1.5 cm) meant for holding one test individual in each hole, were prepared as follows. Multidishes and rubber plugs fitting the holes were submerged in deionized water for 24 hr for reduction of static electricity. After air drying, each multidish hole was filled with 2.65 g of the soil–dimethoate mixture. Because the DIP procedure demands a horizontal background with no places for the animal to hide, the soil had to be compressed. This was done by use of a pestle until a firm and even surface was obtained. Care was taken not to compress the soil too hard, to avoid a wet surface. The multidish holes were sealed immediately with the rubber plugs. Neonate juveniles (0–2 days old) were added to the multidishes, one individual in each hole. Twenty-four individuals were exposed to each concentration, but because the sex ratio in the stock cultures varied, this did not ensure a predetermined number of replicates (e.g., 12 replicates for each sex).

The Collembola were fed two granules of dried bakers yeast each; the food was renewed every second week. The predatory mites were fed 0- to 7-day-old *F. fimetaria* during the first 14 days (until the reproductive age) and subsequently 14- to 21-day-old *F. fimetaria*. Food was added in surplus, and earlier experiments had revealed that supplementing up to 40 prey every third day fulfilled this demand.

Assessment

The multidishes were assessed every third or fourth day. With DIP, the increase in length was determined by measuring the length from the posterior end of the abdomen to the anterior end of the head, between the antennae (Collembola in movement), or the anterior edge of the dorsal shield (predatory mite). The length of both sexes was recorded for individuals from an age of 2–38 days (*F. fimetaria*), 1–37 days (*H. assimilis*), and 2–34 days (*H. aculeifer*). Eggs produced by *H. aculeifer* were recorded and removed.

Evaporation from the multidishes was compensated for by the supplement to every hole of $\frac{1}{24}$ of the average amount of evaporated water from each dish with deionized water once a week. In the experiment with the predatory mite, it was necessary to anesthesize the animals by a weak CO_2 stream to be able to count unconsumed prey. Dead prey was also counted and discarded, and new prey was added up to a total of 40 living prey per hole. At the termination of the experiments, the animals were sexed, which for the Collembola implied mounting on slides for microscopy.

Statistics and Models

Data were analyzed for normality by means of a normality plot and for homogeneity of variance by Bartlett's test. Analysis of variance (ANOVA) was made by Duncan's multiple range test. The fitting of models was evaluated by means of a lack-of-fit test [$F(1,df)$ distributed] (van Eweijk and Hoekstra, 1993). For all tests, the level of significance was 0.05 if not otherwise stated. The procedures of the SAS/STAT program package (SAS Institute Inc., 1988) were adopted.

The following models were adopted and modified to handle different EC_x values: a standard logistic model (van Eweijk and Hoekstra, 1993) and a linear logistic model (Brain and Cousens, 1989).

Modified version of the standard logistic model:

$$y = \frac{k}{1 + \left(\frac{x}{100 - x}\right) \cdot \left(\frac{z}{z_0}\right)^c}, \qquad (1)$$

where x is % effect, z is concentration, z_0 is EC_x, k is value of y at $z = 0$, c is constant, and relates to the slope of the tangential line in the point of inflection, where $x = EC_{50}$.

Modified version of the linear logistic model:

$$y = \frac{k(1 + fz)}{1 + \left(\left(\frac{100}{100 - x}\right) \cdot (fz_0 + 1) - 1\right) \cdot \left(\frac{z}{z_0}\right)^c}, \qquad (2)$$

where k is value of y at $x = 0$, z_0 is EC_x (reduction), f is hormesis constant, and other symbols are as in Eq. (1).

Reductive EC_x values and the corresponding confidence interval were estimated by means of nonlinear regression procedures using a modified version of the program of van Eweijk and Hoekstra (1993) in the SAS procedure PROC NLIN (SAS Institute Inc., 1988). If EC_x values for stimulation were required, $-x$ was used in Eq. (2).

Two growth models were adopted for fitting the length data of individuals of each sex for each concentration: the logistic model and the model of von Bertalanffy (Fig. 1).

RESULTS

All three species displayed a sexual dimorphism for body length, which started to be expressed in the juveniles at age 10–15 days old (*F. fimetaria*), ≤10 days old (*H. assimilis*), and 5–10 days old (*H. aculeifer*) (Figs. 2, 3, and 4). This held true for untreated as well as dimethoate-treated individuals, and in all cases females grew longer than males. Because a species-specific response to dimethoate was observed, the three species are treated separately in the following.

Folsomia fimetaria

No mortality was observed in the controls during the first 4 weeks, and at the end of the experiment mortality was still less than 10%. Despite the low concentrations of dimethoate chosen for chronic effect studies, mortality in the exposed individuals increased with time as a consequence of the relatively long period of the experiment (38 days). Only individuals surviving the entire experiment were included in the data treatment.

The overall growth pattern was similar in both sexes, resulting in curves of sigmoid shape. The length of males, however, tended to stabilize earlier than that in the females (see Fig. 2 for a representative set of dimethoate concentrations). Length of females was slightly reduced at increasing concentrations (Fig. 5). Only at the highest concentration, 0.3 mg/kg, was length significantly lower than in the controls, when aged 9–20 days. Male length was slightly increased at the lowest concentration (0.029 mg/kg), whereas lengths at the higher concentrations did not differ from those in the controls (Fig. 5).

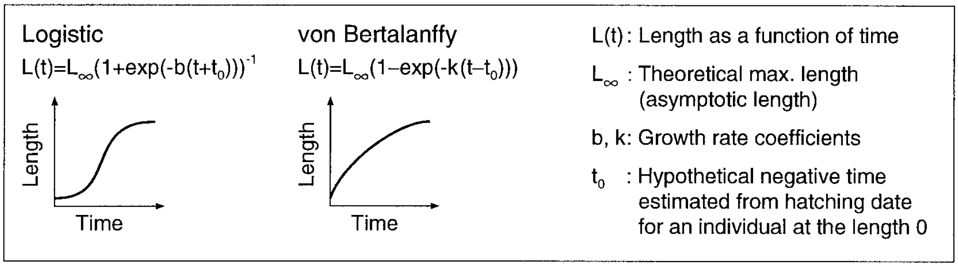

FIG. 1. Growth models after von Bertalanffy (1960), Kaufmann (1981), and Bengtsson *et al.* (1983).

The logistic model (Fig. 1) fitted the data for both sexes at all concentrations. In the males, the test probabilities of the lack-of-fit tests were $0.17 \leqslant P \leqslant 1$, and in the case of females $0.5 \leqslant P \leqslant 0.96$. The model of von Bertalanffy (Fig. 1) was rejected for both sexes, because test probabilities for some of the concentrations were less than 0.05. The growth rate coefficient b of the logistic model was used as a description of growth rate of the individual. By fitting a modified version of the standard logistic model (Eq. 1) to the growth rate coefficients b from the individual growth curves for all concentrations in the females (Fig. 6), the effect concentration of 10% reduction (EC_{10}) was estimated (Table 1). Despite a slightly stimulative effect on b at the lower concentrations in the males (data not presented), this was not significantly different from the control, and no further modeling was considered justified. For both sexes, the estimated asymptotic length (L_∞) was not significantly influenced by dimethoate (data not presented).

Hypogastrura assimilis

As a profound mortality in this species occurred from an age of 28 days to 37 days (30% in the controls), treatment of growth data was limited to animals surviving for at least 28 days. The growth pattern of the two sexes was similar resulting in curves of concave shape (Fig. 3). Comparison of length between doses for the females revealed only a slight increase in length at the middle concentrations (Fig. 7). This was significantly different from the controls only when aged 14 days (adulthood) (0.051 and 0.093 mg/kg) and 20 days (0.051 mg/kg). Thus, the effect was leveled out as time progressed. At the highest concentration (0.3 mg/kg), no reduction in length was observed. Because preliminary tests had revealed a high mortality of *H. assimilis* exposed to dimethoate concentrations above 0.3 mg/kg [LC_{50} = 0.40 mg/kg (0.27–0.58 mg/kg)] after 28 days, growth in females did not seem much affected by the applied concentrations of dimethoate. No significant differences were observed when comparing length between doses in the males, and no dose-dependent trend could be discerned (Fig. 7).

The appropriateness of the growth models in Fig. 1 for fitting the length data gave the following results. The logistic model fitted the data for all concentrations in both sexes. In males, the test probabilities were $0.12 \leqslant P \leqslant 0.98$, and in females, $0.17 \leqslant P \leqslant 0.95$. The model of von Bertalanffy also

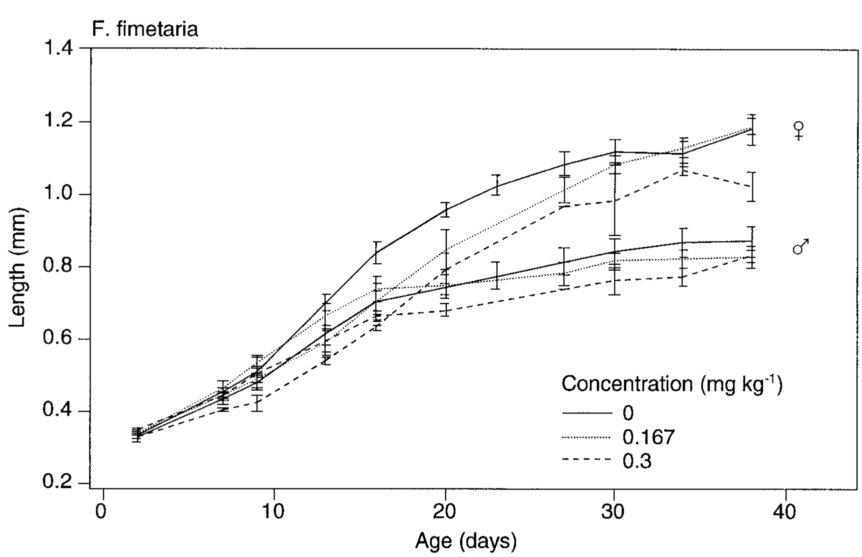

FIG. 2. Growth of *F. fimetaria* males and females exposed to three representative concentrations of dimethoate mg/kg soil. Vertical bars indicate SEM.

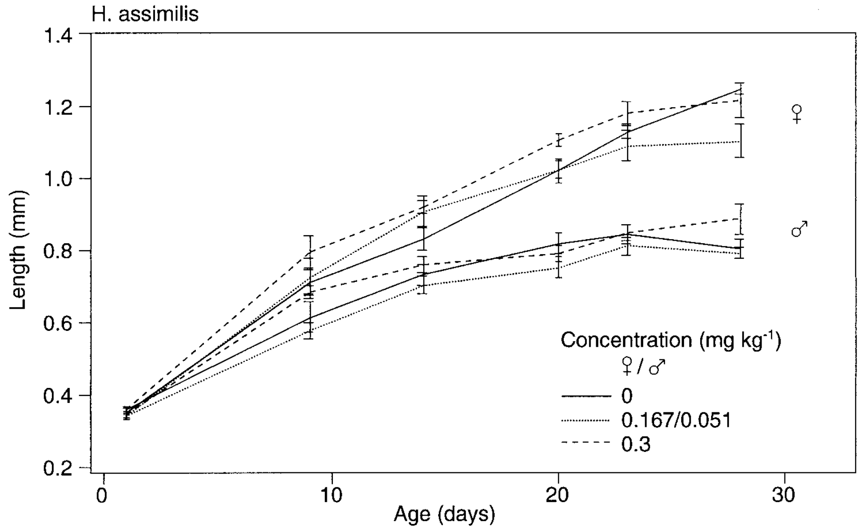

FIG. 3. Growth of *H. assimilis* males and females exposed to three representative concentrations of dimethoate (mg/kg soil). Vertical bars indicate SEM.

fitted the data for all concentrations with test probabilities for the male data, $0.21 \leqslant P \leqslant 0.96$, and for the female data, $0.36 \leqslant P \leqslant 0.99$. Comparison of the growth rate coefficient k of von Bertalanffy (parallel to the parameter b of the logistic model) between concentrations did not reveal any significant difference for either sex. Regarding the growth rate coefficient b of the logistic model, a comparison between concentrations only revealed significant differences in the females, in which a significant increase in b at 0.167 mg/kg dimethoate compared to the controls was observed (data not presented).

Hypoaspis aculeifer

The male sex of *H. aculeifer* was represented by too few individuals (two to four in each concentration) for proper statistical treatment, and this part of the study will receive only a few comments. The growth pattern of the two sexes was similar, resulting in curves of concave shape (Fig. 4). For the females, an increase in length at the lower concentrations and a decrease in length at the highest concentration compared to the controls were observed during the juvenile period and beginning of adulthood (16 days old) (Fig. 8).

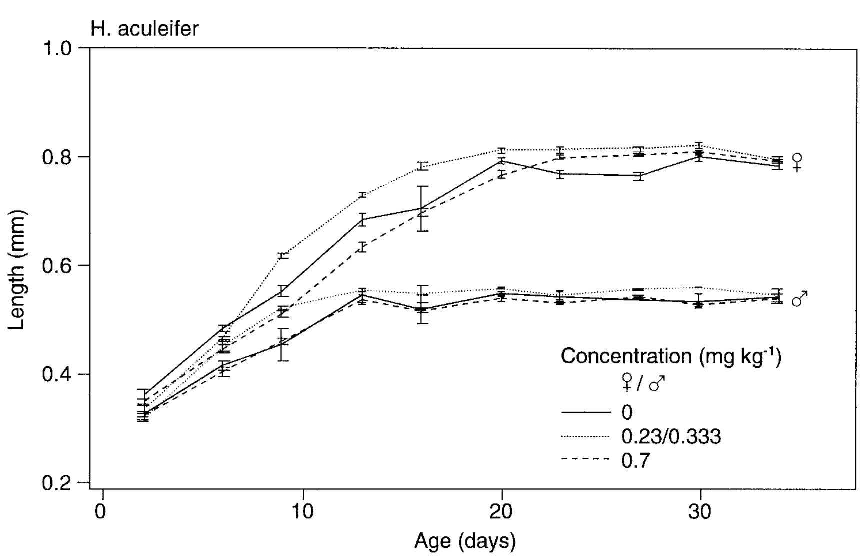

FIG. 4. Growth of *H. aculeifer* males and females exposed to three representative concentrations of dimethoate (mg/kg soil). Vertical bars indicate SEM.

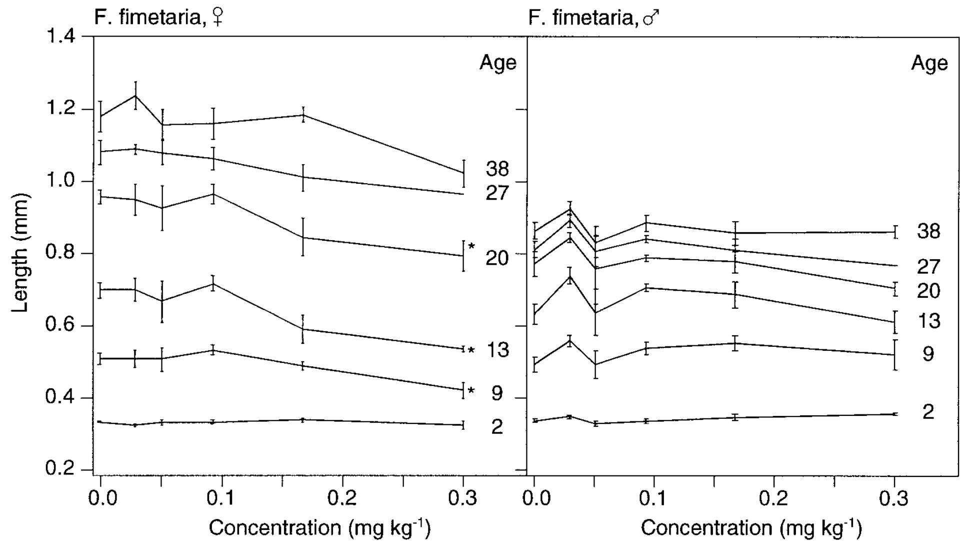

FIG. 5. Mean length of male and female *F. fimetaria* exposed to a range of dimethoate concentrations (mg/kg soil). Age of individuals are indicated at each curve. Vertical bars indicate SEM; asterisks indicate significant difference from control.

When aged 30–34 days, the effect was less obvious. By fitting growth models (Fig. 1) to the female length data, it was demonstrated that the logistic model fitted the data better than the model of von Bertalanffy. The fitting was not excellent but acceptable according to the test probabilities of a lack-of-fit test ($0.09 \leqslant P \leqslant 0.14$). There were significant differences in the growth rate coefficient *b* of the logistic model at several concentrations compared to the controls, and the modified version of the linear logistic model (Eq. 2), allowing for stimulative effects, was fitted to this parameter (Fig. 9). The use of this model made it possible to estimate the different concentrations in which 10% stimulation or inhibition occurred (Table 1). The estimated asymptotic length (L_∞) of the logistic growth model for the females was significantly larger at the lower concentrations and at the highest concentration (0.7 mg/kg) compared to the control (data not presented).

The onset of reproduction and fecundity, measured as cumulative egg production in females, was recorded. The first eggs were noted at females aged 16 days in all treatments. Compared to the controls, a continuous significantly increased cumulative egg production was noted in the middle concentration (0.333 mg/kg) and a corresponding decrease at the highest concentration (0.7 mg/kg) in females aged 20 days and onwards (Fig. 10). By fitting the modified version of the linear logistic model (Eq. 2) to the cumulative egg production by females aged 20–34 days (Fig. 10), effect concentrations of stimulation and inhibition were estimated (Table 1). During this period, the stimulative effect was constant and the inhibitory effect decreased (increasing EC_{10} values).

DISCUSSION

Final Length

The length of the adults at the termination of the experiments was unaffected by the treatments in both collembolan species, whereas an altered growth rate was demonstrated in the females of *F. fimetaria.* The observation of the same phenomenon in heavy metal-exposed Collembola by Tranvik *et al.* (1993) and Crommentuijn *et al.* (1993) indicates either a common mechanism for the effect of these very different chemicals on the growth of Collembola or a more general ability in the Collembola for compensation. The last explanation is in agreement with the statements of Hubbell (1971) that organisms have built-in mechanisms for evaluating their growth performance and for modifying energy intake and expenditure to compensate for performance ''errors'' as a result of environmental or physical disturbances.

Age-Specific Length and Growth Rate

A sex- and species-specific difference was observed when evaluating growth by comparison of length measurements at different ages and through modeling of the growth and usage of the logistic growth rate coefficient *b*. The existence of the sexual dimorphism, expressed by the length data, indicated the importance of sexual identification of the individuals when using size as an effect parameter (endpoint); otherwise, effects might be concealed.

In the interpretation of the growth data of *H. assimilis,* attention has to be paid to the difficulties in handling this species. The plasticity of the individual made measurements of length rather difficult. The significant increase in the

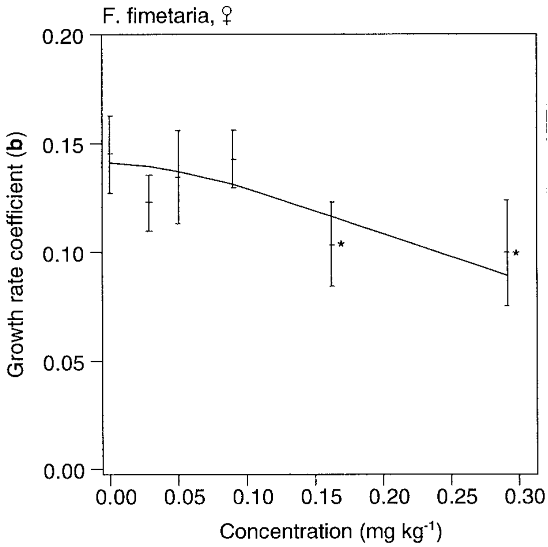

FIG. 6. Mean growth rate coefficient *b* (logistic model) of female *F. fimetaria* as a function of dimethoate concentration (mg/kg soil). Vertical bars indicate SEM; asterisks indicate significant difference from control.

growth rate coefficient *b* at 0.167 mg dimethoate/kg in the females is not regarded as a major effect or point of concern because no such effect was observed with the corresponding parameter *k* of von Bertalanffy. Furthermore, no statistical divergences were observed when comparing length measurements at 0.167 mg/kg with the controls (Fig. 7). For males of *H. assimilis,* there was no trend observed when comparing the growth rate coefficient *b* to any of the age-specific length measurements.

For certain age classes of female *F. fimetaria* and *H. aculeifer,* the response of length to different concentrations of dimethoate correlated well with the response expressed by the growth rate coefficients. However, the response of length varied between some of the age classes, which indicated that length was a less robust growth parameter. As opposed to the age-specific response to dimethoate, viz. by length, the growth rate coefficient *b* served as a more conservative growth parameter. The growth rate coefficient holds information of the entire progression of growth and, thus, is considered the most powerful parameter usable as an endpoint for *F. fimetaria* and *H. aculeifer.*

Growth in Relation to Other Fitness Parameters

Dimethoate had no effect on the onset of parthenogenetic reproduction in *H. aculeifer* at the tested concentrations. Significant stimulating and inhibitory effects on growth rate and egg production were, however, observed at the lower and the highest tested concentrations. A stimulative effect of dimethoate on fertility (number of offspring) of *H. aculeifer* was also demonstrated by Krogh (1995) at the same concentration range. Thus, a subtoxic stimulation (hormesis) of three different parameters caused by near-identical concentrations of dimethoate has been demonstrated in *H. aculeifer.* A review of and explanations for hormetic growth effects have been given by Stebbing (1982).

A similar coherence of toxic effects on growth and reproduction in *F. fimetaria* can be derived from the present growth data and data on effects of dimethoate on fertility (number of offspring) (Løkke *et al.,* 1994). The two parameters, growth and fertility, were affected to the same extent when tested during a period of 38 and 28 days, respectively (EC_{10} = 0.1 mg dimethoate per kilogram soil for both parameters).

Exposure

Exposure of individuals to dimethoate was intended through the soil (soil water). In the experiments with the Collembola, exposure through the food may have also occurred because the dried yeast pellets readily absorbed moisture when applied to the soil surface. Bioconcentration of dimethoate by yeast (*S. cerevisiae*) in liquid culture has been

TABLE 1
Effect of Concentrations of Dimethoate (mg/kg Soil) of the Parameters: Growth Rate Coefficient *b* (Logistic Model) (*F. fimetaria* and *H. aculeifer*) and Cumulative Egg Production (*H. aculeifer*)

Species	Parameter	Period (age of individual in days)	Effect concentration (mg/kg soil)
F. fimetaria ♀	Growth rate coefficient *b*	2–38	EC_{10}: 0.11 [0.014; 0.21]
H. aculeifer ♀	Growth rate coefficient *b*	2–34	EC_{+10}: 0.044 [0.039; 0.048]
			EC_{10}: 0.59 [0.51; 0.67]
	Cumulative egg production	16–20	EC_{10}: 0.55 [0.49; 0.61]
		16–23	EC_{10}: 0.59 [0.53; 0.65]
		16–27	EC_{10}: 0.65 [0.58; 0.76]
		16–34	EC_{10}: 0.68 [0.61; 0.76]

Note. EC_{10}, lowest concentration at which a 10% reduction occurs. EC_{+10}, lowest concentration of 10% stimulation. 95% confidence intervals in brackets.

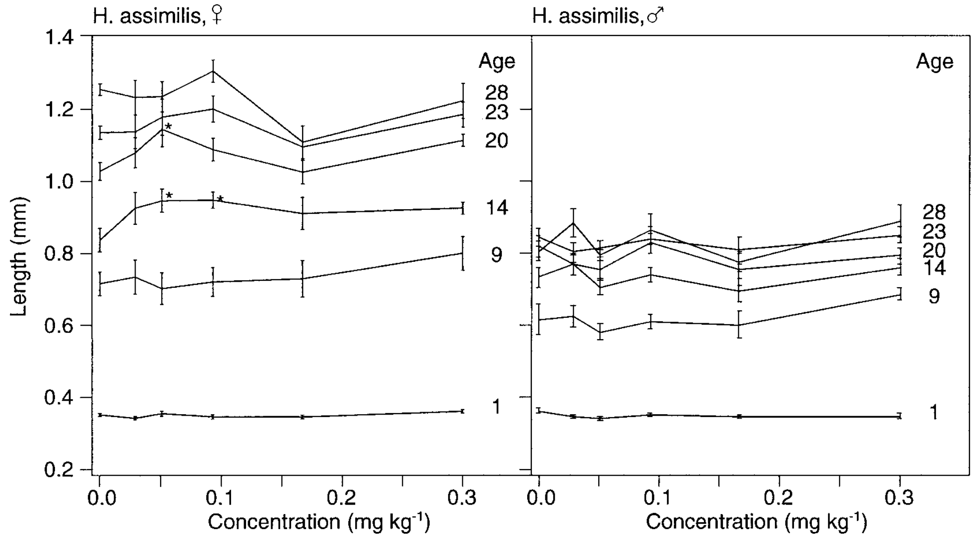

FIG. 7. Mean length of male and female *H. assimilis* exposed to a range of dimethoate concentrations (mg/kg soil). Age of individuals are indicated at each curve. Vertical bars indicate SEM; asterisks indicate significant difference from control.

observed by Kumar *et al.* (1989). They observed a rapid bioconcentration that was inversely proportional to the treatment level: when exposed to 1 μg dimethoate/ml, a 330× magnification in 6 hr was observed, followed by a rapid decline to six× magnification in another 6 hr. An actual growth of the applied dried yeast in the present experiments and the potential of accumulating dimethoate under the present circumstances are, however, unknown. To gain insight into the actual duration of exposure to dimethoate via the soil, comparison was made to data on half-lives of dimethoate in different soil types given by Kolbe *et al.* (1991). They reported half-lives of dimethoate ranging from 4.8 to 9.7 days, when applied at 3 or 4 mg/kg dry soil to three different soils at 20°C. When compared to the soil being used in the current experiments, which contained on average 1.6% org. C, a half-life of dimethoate of 5–8 days would be expected. El Beit *et al.* (1977) have, however, found the retention of dimethoate to be dependent on dosage, and because several other factors might influence the persistence of the com-

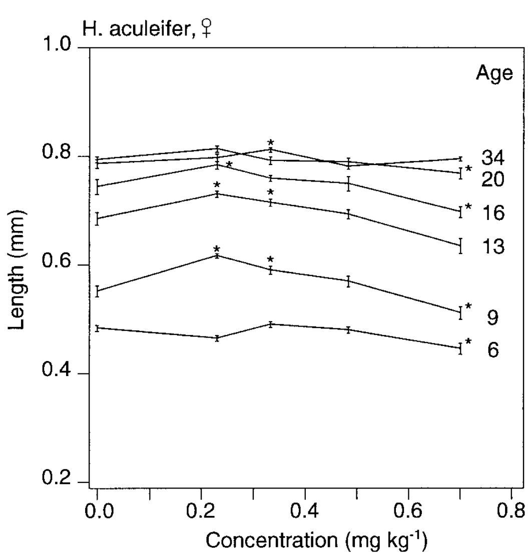

FIG. 8. Length of female *H. aculeifer* exposed to a range of dimethoate concentrations (mg/kg soil). Age of individuals are indicated at each curve. Vertical bars indicate SEM; asterisks indicate significant difference from control.

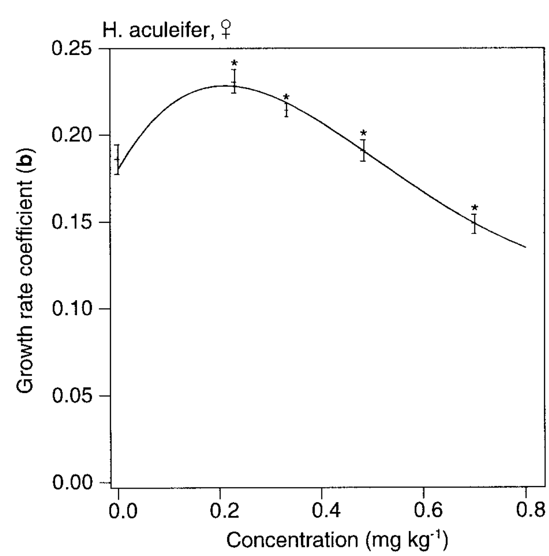

FIG. 9. Mean growth rate coefficient *b* (logistic model) of *H. aculeifer* females as a function of dimethoate concentration (mg/kg soil). Vertical bars indicate SEM; asterisks indicate significant difference from control.

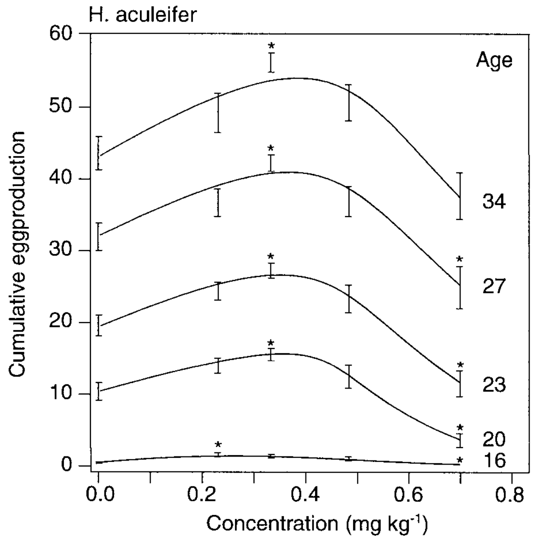

FIG. 10. Mean cumulative egg production by *H. aculeifer* females aged 20–34 days as a function of dimethoate concentration (mg/kg soil). Age of individuals are indicated at each curve. Vertical bars indicate SEM; asterisks indicate significant difference from control.

pound, a lower half-life in the present soil may be the case. When combining this information with the effect concentrations in Table 1, *F. fimetaria* is potentially not only acutely at risk, but also at risk regarding growth performance for a considerable time period postapplication of dimethoate at recommended dosages in the field. In the same circumstances, *H. aculeifer,* on the contrary, is stimulated with regard to growth and reproduction. A similar stimulation of consumption may have consequences for the population of this species as well as for Collembolan prey surviving the chemical.

These hypotheses must disregard the differences in the laboratory system compared to the field situation (temperature, avoidance behavior, etc.).

Growth Modeling

For the description of growth in several Collembolan species, the growth model of von Bertalanffy has been the most widely used (Petersen, 1971; Walsh and Bolger, 1990; Ernsting *et al.,* 1993; Posthuma *et al.,* 1993; Tranvik *et al.,* 1993). The model has been criticized, though, for being too rigid—not taking into consideration that growth is not an entirely passive process—and that it does not allow for compensations for disturbances (Calow, 1976). As the authors found, the model does not pay attention to the general growth pattern of the very young juveniles. The growth pattern of juveniles is generally characterized by a lag phase followed by a steep increase, resulting in a curve of sigmoid shape. The progression of growth in the juvenile period, which was of most importance in this study, was in some (but not all) cases better described by the logistic model. As also stated by Tranvik *et al.* (1993), the model of von Bertalanffy is relatively insensitive to the stabilization of the asymptotic body size. These findings support some of the criticism of the von Bertalanffy model; however, depending on the purpose, the model can be quite useful.

Despite a better fit of the logistic model to the length data of *H. aculeifer,* this model apparently also does not allow for compensations of disturbances regarding the final length (L_∞) as seen when comparing Figs. 8 and 9.

CONCLUSION

A sex- and species-specific difference in sensitivity toward dimethoate was exhibited in the three tested microarthropods.

For *H. aculeifer* and *F. fimetaria,* effects of dimethoate on growth and reproduction were within the same order of magnitude for each species.

It can be concluded that the logistic model and the model of von Bertalanffy are usable for the description of growth in the two Collembolan species and the predatory mite species, but the logistic model gives a better fit to the data of the individual juvenile growth and thereby is more useful for detecting differences in, e.g., growth rates caused by anthropogenic pollutants or abiotic factors.

Juvenile growth rate in *F. fimetaria* and *H. aculeifer,* separated by sex, may be suggested as an ecotoxicological test parameter with the logistic growth rate parameter *b* as endpoint. A feasible test procedure, however, requires further development of the test.

ACKNOWLEDGMENTS

The authors thank Karen Kjær Jacobsen and Zdenek Gavor for excellent technical assistance and Bjarne Christensen for advice in statistics and modeling. This project received financial support from The EC Environmental Research Programme Contract EV5V-CT92-0218 and The Danish Environmental Research Programme.

REFERENCES

Anonymous (1989). Dimethoate. In *Environmental Health Criteria,* Vol. 90, pp. 1–85. WHO, Geneva.

Badejo, M. A., and Van Straalen, N. M. (1992). Effects of atrazine on growth and reproduction of *Orchesella cincta* (Collembola). *Pedobiologia* **36,** 221–230.

Bengtsson, G., Gunnarsson, T., and Rundgren, S. (1983). Growth changes caused by metal uptake in a population of *Onychiurus armatus* (Collembola) feeding on metal polluted fungi. *Oikos* **40,** 216–225.

Brain, P., and Cousens, R. (1989). An equation to describe dose responses where there is stimulation of growth at low doses. *Weed Res.* **29,** 93–96.

Calow, P. (1976). Biological machines a cybernetic approach to life. In *Special Topics in Biology Series,* pp. 58–61. Arnold, sevenoaks.

Crommentuijn, T., Brils, J., and Van Straalen, N. M. (1993). Influence of cadmium on life-history characteristics of *Folsomia candida* (Willem) in an artificial soil substrate. *Ecotoxicol. Environ. Saf.* **26,** 216–227.

De Jong, J. H., Lobbes, P. V., and Bolland, H. R. (1981). Karyotypes and sex determination on two species of laelapid mites (Acari: Gamasida). *Genetica* **55,** 187–190.

El Beit, I. O. D., Wheelock, J. V., and Cotton, D. E. (1977). Factors affecting the fate of dimethoate in soil. *Int. J. Environ. Stud.* **11,** 113–124.

El Beit, I. O. D., Wheelock, J. V., and Cotton, D. E. (1978). Factors influencing the degradation of dimethoate in soils and solutions. *Int. J. Environ. Stud.* **11,** 253–260.

Ernsting, G., Zonneveld, C., Isaaks, J. A., and Kroon, A. (1993). Size at maturity and patterns of growth and reproduction in an insect with indeterminate growth. *Oikos* **66**(1), 17–26.

Hubbell, S. P. (1971). Of sowbugs and systems: The ecological bioenergetics of a terrestrial isopod. In *Systems Analysis and Simulation in Ecology* (B. C. Patten, Ed.), Vol. 1, pp. 269–324. Academic Press, New York.

Joy, V. C., and Chakravorty, P. P. (1991). Impact of insecticides on nontarget microarthropod fauna in agricultural soil. *Ecotoxicol. Environ. Saf.* **22,** 8–16.

Kaufmann, W. (1981). Fitting and using growth curves. *Oecologia* **49,** 293–299.

Kolbe, A., Bernasch, A., Stock, M., Schütte, H. R., and Dedek, W. (1991). Persistence of the insecticide Dimethoate in three different soils under laboratory conditions. *Bull. Environ. Contam. Toxicol.* **46,** 492–498.

Kristensen, H., Permin, O., Nielsen, G. C., Jørgensen, L. N. (Eds.) (1993). *Vejledning i planteværn.* Statens Planteværnscenter, Landskontoret for planteavl. Landbrugets informationskontor.

Krogh, P. H. (1995). Effects of pesticides on the reproduction of *Hypoaspis aculeifer* (Gamasida: Laelapidae) in the laboratory. *Acta Zool. Fennica* **196,** 333–337.

Kumar, S., Dhanaraj, P. S., and Bhatnagar, P. (1989). Bioconcentration and effects of dieldrin, dimethoate, and permethrin on *Saccharomyces cerevisiae. Bull. Environ. Contam. Toxicol.* **43,** 246–253.

Leon, C. D., and Van Gestel, C. A. M. (1994). *Selection of a Set of Laboratory Ecotoxicity Tests for the Assessment of Chemicals in Terrestrial Ecosystems.* Discussion paper, report No. D94004. Vrije Universiteit, Amsterdam.

Løkke, H., and Van Gestel, C. A. M. (Eds.) (1993). *Manual of SECOFASE, Development, Improvement and Standardization of Test Systems for Assessing Sublethal Effects of Chemicals on Fauna in the Soil Ecosystem,* pp. 41. Report from a workshop held in Silkeborg, Denmark, January 18–19, 1993. National Environmental Research Institute.

Løkke, H., Krogh, P. H., Folker-Hansen, P., and Holmstrup, M. (1994). Development of single and two-species sublethal tests on *Hypoaspis aculeifer* (Acari: Gamasida) and *Folsomia fimetaria* (Collembola: Isotomidae). In *Progress Report 1993 of SECOFASE, Second Technical Report. Development, Improvement and Standardization of Test Systems for Assessing Sublethal Effects of Chemicals on Fauna in the Soil Ecosystem* (J. A. Wiles, J. E. Kammenga, and H. Løkke, Eds.), pp. 94. Report from a workshop held in Braunschweig, Germany, December 6–7, 1993. National Environmental Research Institute, Denmark.

Petersen, H. (1971). Methods for estimation of growth of collembola in cultures and in the field, exemplified by preliminary results for Onychiurus furcifer (Börner). IV Colloquium Pedobiologiae, Dijon 1970. *Ann. Zool. Ecol. An. (hors série),* 235–254.

Posthuma, L., Verweij, R. A., Widianarko, B., and Zonneveld, C. (1993). Life-history patterns in metal-adapted Collembola. *Oikos* **67,** 235–249.

Sardar, M. A., and Murphy, P. W. (1987). Feeding tests of grassland soil-inhabiting gamasine predators. *Acarologia* **28**(2), 117–121.

SAS Institute Inc. (1988). *Release 6.03 Edition,* pp. 1028. SAS Institute Inc., Cary, NC.

Schiemer, F. (1982). Food dependence and energetics of freeliving nematodes. I. Respiration, growth and reproduction of *Caenorhabditis briggsae* (Nematoda) at different levels of food supply. *Oecologia* **54,** 108–121.

Springett, J. A., and Gray, R. A. J. (1992). Effect of repeated low doses of biocides on the earthworm *Aporrectodea caliginosa* in laboratory culture. *Soil Biol. Biochem.* **24**(12), 1739–1744.

Stebbing, A. R. D. (1982). Hormesis—The stimulation of growth by low levels of inhibitors. *Sci. Total Environ.* **22,** 213–234.

Tranvik, L., Bengtsson, G., and Rundgren, S. (1993). Relative abundance and resistance traits of 2 Collembolan species under metal stress. *J. App. Ecol.* **30**(1), 43–52.

Usher, M. B., and Stoneman, C. F. (1977). *Folsomia candida*—An ideal organism for population studies in the laboratory. *J. Biol. Ed.* **11**(2), 83–90.

Van Ewijk, P. H., and Hoekstra, J. A. (1993). Calculation of the EC50 and its confidence interval when subtoxic stimulus is present. *Ecotox. Environ. Saf.* **25,** 25–32.

Van Straalen, N. M., Schobben, J. H. M., and De Goede, R. G. M. (1989). Population consequences of cadmium toxicity in soil microarthropods. *Ecotoxicol. Environ. Saf.* **17,** 190–204.

Van Straalen, N. M., Leeuwangh, P., and Strotelder, P. B. M. (1994). Progressing limits for soil ecotoxicological risk assessment. In *Ecotoxicology of Soil Organisms* (M. H. Donker, H. Eijsackers, and F. Heimbach, Eds.), pp. 411–425. Lewis Publishers, London.

Von Bertalanffy, L. (1960). Principles and theory of growth. In *Fundamental Aspects of Normal and Malignant Growth* (W. W. Nowinski, Ed.), pp. 137–259. Elsevier, Amsterdam/New York.

Walsh, M. I., and Bolger, T. (1990). Effects of diet on the growth and reproduction of some collembola in laboratory. *Pedobiologia* **34,** 161–171.

Walter, D. E., and Oliver, J. H. (1989). *Geolaelaps oreithyiae,* n.sp. (Acari: Laelapidae), a thelytokous predator of arthropods and nematodes, and a discussion of clonal reproduction in the mesostigmata. *Acarologia* **30**(4), 293–303.