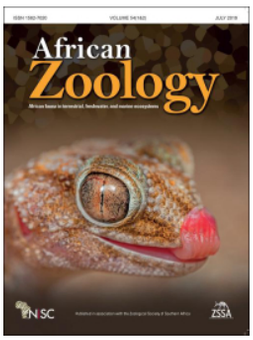

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The life-cycle of the compost worm *Eisenia fetida* (Oligochaeta)

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To determine the full potential of the compost worm *Eisenia fetida* as waste processor and as source of protein, the life-cycle of this species had to be studied thoroughly. The development, growth and reproduction of *Eisenia fetida* were studied on cattle manure under favourable conditions of moisture, temperature and nutrition. Data were gathered over a period of 600 days. Apart from the life-cycle this study also indicated that this species can be reproductively active for more than 500 days. This is significantly longer than had previously been believed. Each cocoon produced a mean of 2,7 hatchlings after a mean incubation period of 23 days. These worms attained sexual maturity after 40 to 60 days and produced their first cocoons within four days after mating took place.

Ten einde die volle potensiaal van die komposwurm *Eisenia fetida* as afvalverwerker en as proteïenbron vas te stel, moes die lewensloop van hierdie spesie deeglik bestudeer word. Die ontwikkeling, groei en voortplanting van *Eisenia fetida* is op beesmis bestudeer onder gunstige vog-, temperatuur- en voedingstoestande. Gegewens is oor 'n periode van 600 dae ingewin. Naas die lewensloop het hierdie ondersoek getoon dat die spesie vir meer as 500 dae voortplantingsproduktief kan wees. Dit is aansienlik langer as wat tot dusver vermoed is. Elke kokon het gemiddeld 2,7 nakomelinge voortgebring na 'n gemiddelde inkubasieperiode van 23 dae. Hierdie wurmpies was binne 40–60 dae geslagsryp en het binne vier dae na paring begin om kokonne te produseer.

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The potential utility value of terrestrial Oligochaeta enjoys a great deal of attention. Research is primarily aimed at two fields, viz. protein production (Schultz & Graff 1977; Sabine 1983 and Knieriemen 1985) and waste processing (Graff 1974; Tsukamoto & Watanabe 1977; Neuhauser, Hartenstein & Kaplan 1980; Kaplan, Hartenstein, Neuhauser & Malecki 1980; Knieriemen 1985 and Haimi & Huhta 1986). The feasibility of using vermiculture as biotechnology for waste control and protein production, is dependent, amongst others, on a fundamental knowledge of the life-cycle of the earthworms capable of waste processing. As the concern is largely with number and biomass, a thorough knowledge of the growth rate and reproductive potential of the relevant species is a prerequisite.

Although it is accepted that most aspects concerning the life-cycle of the compost worm *Eisenia fetida* are known, lacunae and contradictions occur generally when it comes to matters of detail. Relatively few results with regard to long-term observations and conditions under which these were obtained are available on aspects such as survival, growth and the duration of the period of cocoon production. Among the results that are available some rest on extrapolations of results gained over a relatively short period. The life expectancy of *Eisenia fetida* under controlled conditions varies, according to different authors, between one and five years (Reynolds 1977; Edwards & Lofty 1977). With regard to cocoon production Evans & McGuild (1948) report an average of 3,8 cocoons per week, Edwards, Burrows, Fletcher & Jones (1984) report 2–5 cocoons per week, Neuhauser, Hartenstein & Kaplan (1980) 2 per week and Graff (1982) 3 cocoons per week per individual. According to Neuhauser, Hartensein & Kaplan (1980) the reproductive phase in the life of *Eisenia fetida* is between 30 and 40 weeks with a peak in cocoon production between 9 and 11 weeks. They claim, however, that *Eisenia fetida* can possibly produce cocoons for a whole year.

The purpose of this study was to determine the life-cycle of the compost worm *Eisenia fetida* on an organic nutritive source, viz. cattle manure under favourable conditions of moisture, provision of nutrition and temperature. Results are provided which were obtained over a period of 600 days with regard to survival, growth rate, cocoon production period, total number of cocoons produced, incubation period of cocoons and number of offspring per cocoon.

The results of this study brought to light that *Eisenia fetida* can be reproductively active for a significantly longer period than had been considered feasible in the literature on the subject. The total life-cycle is now, for the first time, rendered fully.

Materials and Methods

Pure cattle manure without any straw and free of urine and about 30 days old, was used as a nutritive medium. This medium was prepared by finely grinding the cattle manure and by sifting this through a sieve with a 500 μm mesh size. The reason for this is that Neuhauser, Kaplan, Malecki & Hartenstein (1980) found a link between the size of the food particles and the rate of mass increase of worms. Smaller food particles give rise to a more rapid growth rate. Distilled water was added to the nutritive medium in order to create a moisture content of about 75%. Reinecke & Venter (1987) found that a moisture content of 75% was favourable to the growth and reproduction of *Eisenia fetida*. The nutritive medium (320 g wet mass) was placed in a glass fibre bowl

of 1 500 cm and left to stabilize for 24 h.

Ten newly hatched specimens of *Eisenia fetida* were gathered from a Petri dish in which cocoons had been placed to hatch. After the biomass of the worms had been determined individually, they were placed in the nutritive medium. The container with the ten specimens of *Eisenia fetida* were left in an environmental control cabinet at a constant temperature of 25°C and a relative humidity of 80% for the full duration of the study (600 days). Reinecke & Kriel (1980) found that 25°C was the most suitable temperature for cocoon production. The survival and the biomass of the worms were determined every 10 days with the exception of the first 10 days, when the worms were still very small. During the first 60 days no fresh food was added, which led to a very slow initial growth of the worms. From day 60 onwards a part of the old substrate was replaced by fresh nutritive medium (cattle manure of the same origin as that with which the experiment was begun, and of which the age varied between 10 and 20 days). The addition of fresh food occurred every 10 to 20 days, with the result that a relatively favourable nutritive milieu was maintained throughout. The removal of a part of the old substrate could have prevented the excreta from accumulating to harmful levels (Kaplan *et al.* 1980). The moisture content of the nutritive medium was determined for every 10 days, and was maintained at a level of between 70% and 80% for the duration of the experiment.

After cocoon production had begun (from day 70) the nutritive medium was searched for cocoons every two days. The cocoons were counted and the mass determined, following which they were placed in multi-cell containers and covered with distilled water. The cocoons were incubated at 25°C and left to hatch. The incubation period of the cocoons as well as the number of offspring was determined in this way. The incubation period was regarded as the period from when the cocoon was produced until the hatching of the first worm from the cocoon.

Results

Survival and growth of *Eisenia fetida* on cattle manure

Although the newly hatched worms were initially very small and had an average biomass of only 2,8 mg, all 10 survived the initial inoculation in the nutritive medium.

No mortality occurred among these worms for the full duration of the period of investigation, viz. 600 days. The worms initially grew very slowly during the first 60 days (Figure 1), at a mean rate of 2,5 mg per worm per day. From day 60 (when fresh food was added) to day 90, the growth rate of the worms increased at a mean rate of 16 mg per worm per day. From day 90 up to and including the last observation (day 600), a mass increase of 1,6 mg per worm per day occurred. The mean biomass of the worms on day 600 was 1,4 g. Seen over the whole period of observation, a mean growth of 2,5 mg per worm per day occurred. The highest mean biomass which the worms obtained was registered on day 530, when the worms weighed a mean of 1,5 g. The moisture content of the nutritive medium as well as the addition of fresh food is indicated in Figure 1.

Clitellum development and cocoon production

All ten worms used in the study reached sexual maturity within 80 days with the development of a fully developed clitellum. None of the worms revealed any outward sign of a clitellum before 60 days. If it should be brought into account that the nutritive status of the worms had not been optimal during the first 60 days, one could reason that sexual maturity could have been attained sooner. Cocoon formation started within four days after mating had occurred. Cocoon production started 70 days after hatching, and continued after 600 days. Although a

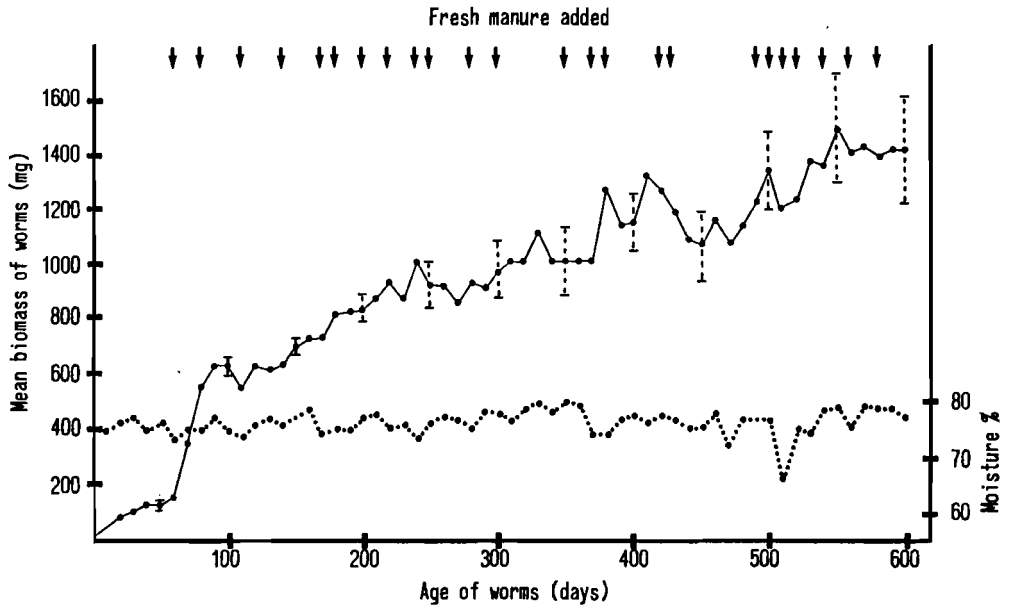

Figure 1 Change in biomass of newly hatched specimens of *Eisenia fetida* reared on cow manure over a period of 600 days at a constant temperature of 25°C. Vertical bars indicate standard deviation.

considerable variation occurred in the rate of cocoon production (Figure 2), cocoon production never halted at any stage. A peak in the production rate occurred in the period between days 80 and 90, with a mean cocoon production of seven cocoons per worm during these 10 days.

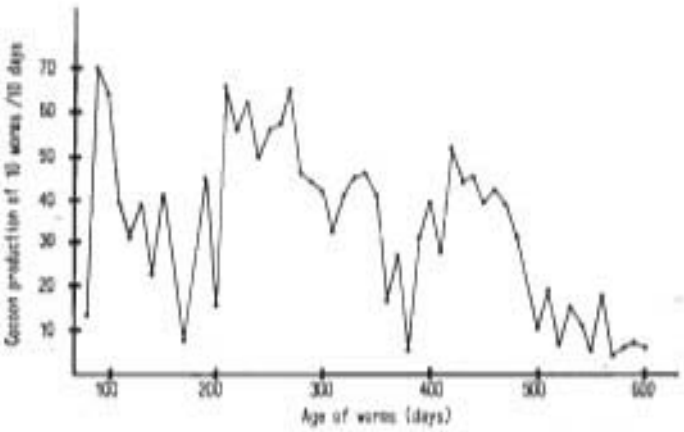

Figure 2 Cocoon production of *Eisenia fetida* over a period of 600 days at a temperature of 25°C.

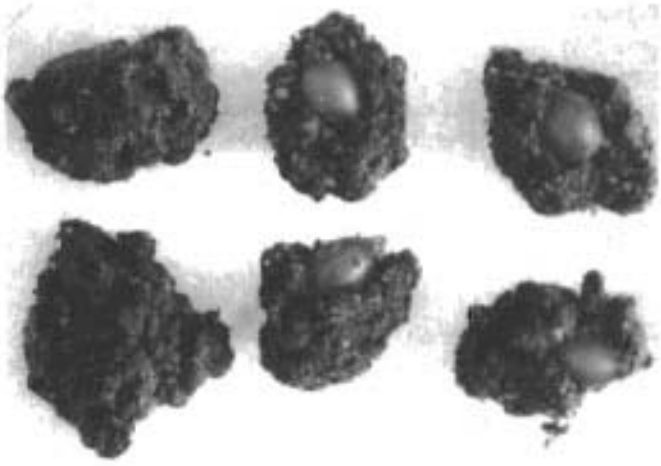

Figure 3 Cocoons of *Eisenia fetida* covered by substrate particles.

With regard to cocoon deposits it was noticeable that cocoons often occurred within substrate clumps (Figure 3). These clumps are probably formed because aggregates or particles of the processed substrate adhere to the mucous layer of the cocoon surface. Moisture loss from the cocoon is probably limited by the surrounding substrate layer, and in so doing contributes to the survival of the worms under unfavourable moisture conditions.

In total 1 725 cocoons were produced by the 10 worms, which represent a mean production rate of 3,5 cocoons per worms per 10-day period over the whole duration of the production period. During the first 12 months of the life-cycle of the worms a mean of 121 cocoons per worm was produced. The mean mass of the cocoons produced during the whole observation period was 14,3 mg. The mass of the cocoons did not, throughout, reveal a linear relation with regard to the biomass of the worms. The total mass of the cocoons produced by the 10 worms was 24,08 g.

Incubation period of cocoons and number of offspring per cocoon

A newly formed cocoon is usually strikingly lighter in colour when compared with older cocoons. As the cocoons near the stage when the worms have to hatch, the cocoons normally turn light brown to red-brown in colour and the young worms become visible through the wall of the cocoon.

The incubation period of 410 cocoons was studied at a constant production and incubation temperature of 25°C. The incubation time of the cocoons varied from 14 tot 44 days with a mean of 23 days as represented in Figure 4.

Eisenia fetida is one of the earthworm species that produces more than one offspring per cocoon. During this study 422 cocoons were studied from which 1 138 worms hatched. In total, 73% of the produced cocoons hatched. The number of offspring per cocoon varied from 1 to 9 with a mean of 2,7 offspring per cocoon for cocoons that hatched. Figure 5 gives a visual résumé of the number of hatchlings per cocoon as well as the percentage occurrence. From Figure 5 one can see that

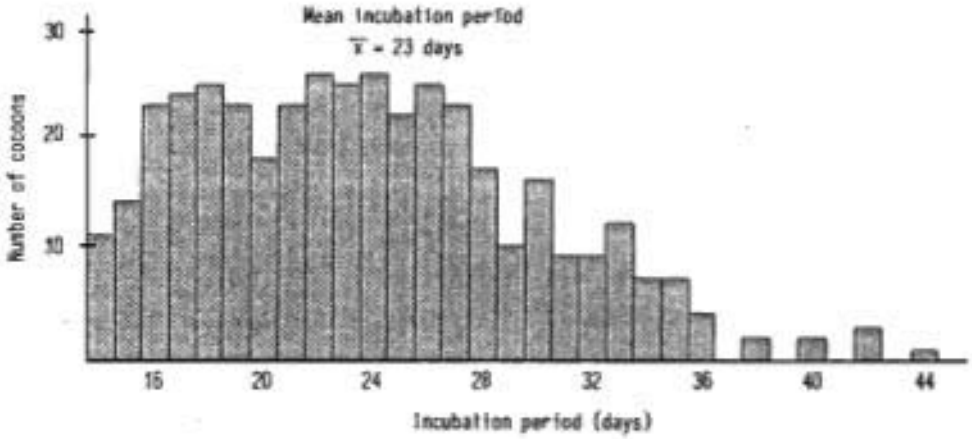

Figure 4 The incubation period of cocoons of *E. fetida* produced and incubated at 25°C.

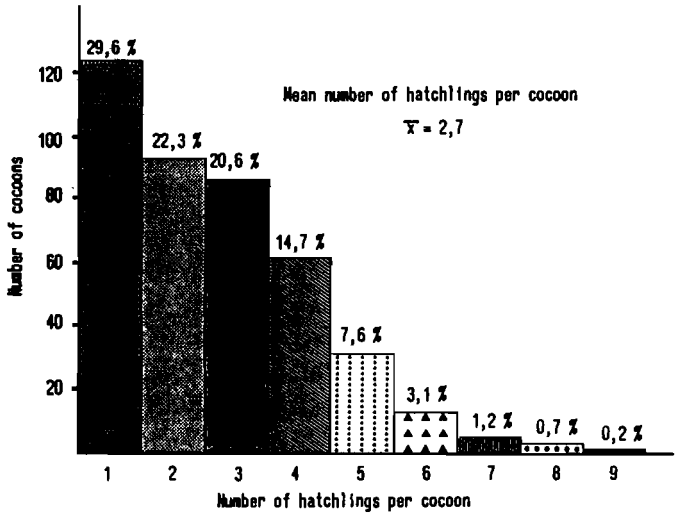

Figure 5 The number of cocoons of *E. fetida* from which different numbers of hatchlings emerged expressed as a percentage of the total cocoon production.

29,6% of the cocoons yielded only one hatchling, while 70,4% of the produced cocoons had more than one offspring.

Discussion

The most important deduction that can be made from the growth curve of *Eisenia fetida* which had fed on cattle manure, is that the worms underwent an increase in biomass over the whole period of study and that a flattening curve towards a plateau had not occurred by day 600 (Figure 1). One cannot deduce a judgment from this observation as to what extent the compost worm could reveal the same sustained growth over a relatively long period of time on a different nutritive medium. The percentage organic material as well as the micro-fauna present differ from waste source to waste source. Growth rate studies on *Eisenia fetida* undertaken by other authors usually stretched over much shorter periods of time. Tsukamoto & Watanabe (1977) based their findings on a study period of 10 weeks, while Loehr, Martin, Neuhauser & Malecki (1984) did observations from 12 to 18 weeks. The results obtained in this study differ from those of Loehr *et al.* (1984) in the sense that there was no decrease in the growth rate after about 10 weeks. The fact that an increase in biomass kept occurring after 500 days could possibly be an indication that the life-span of this species could under favourable conditions even be much more than the two years suspected by Reynolds (1977). The fact that no mortality had occurred during and after the 600 days is a further indication that this species could possibly have a life-span of more than two years.

Two important factors which exerted an influence in this study on the growth rate of the worms, were the moisture content of the nutritive medium and the nutritive status of the worms. A decrease of more than 10% in the moisture content of the substrate gave rise to a drastic reduction in the biomass of the worms as reflected during the period between days 500 and 510 (Figure 1).

Although an effort was made to keep the food that was added identical, it was not possible to determine this. In 66% of the cases where fresh food (organic material content about 60%) was added, it gave rise, within 10 days, to a continued increase in biomass. In the other cases the addition of fresh food led to a decrease in the biomass of the worms in the subsequent period (Figure 1), which indicated that the food which was added was for some reason or other not quite suitable. The suitability and the quality of the food as well as the maintenance of favourable moisture conditions are thus essential for a sustained increase in the growth rate of the compost worm at 25°C.

The influence of population density on growth could not be neglected and was studied separately. The relatively high biomass per worm could have been the result of the low population density used in this study.

If favourable moisture and nutritive conditions are maintained, it can be expected that *Eisenia fetida* will attain sexual maturity within 60 days after hatching. The addition of food on day 60 not only exerted a strong influence on the growth rate of the worms, but also led to a drastic increase in the rate of clitellum development. This gave rise to all 10 worms developing, in the course of 20 days following the more favourable nutritive conditions, to sexual maturity, from which it can be deduced that a favourable nutritive status is a prerequisite for the development of sexual maturity.

The findings of this study with regard to development towards sexual maturity are in accord with the work of Edwards, Burrows, Fletcher & Jones (1984) who found that *Eisenia fetida* takes 7 to 8 weeks to attain sexual maturity, and Neuhauser, Hartenstein & Kaplan (1980) who set this at 4 to 6 weeks for 50% of the individuals and 10 weeks for all the worms at a temperature of 25°C.

Cocoon production among *Eisenia fetida* probably occurs for the largest part of the life-span. Neuhauser, Hartenstein & Kaplan (1980) suspect that *Eisenia fetida* can produce cocoons for a whole year. In our study it was proved that cocoon production can continue for longer than 500 days under favourable conditions. The cocoon production rate of 3,5 cocoons per worm per period of 10 days represents a mean production figure of about 130 cocoons per worm per year. The total production represents a mean cocoon production of 172 cocoons per worm. Cocoon production among compost worms has not been monitored previously for such a long period. The mean incubation period of 23 days of cocoons incubated at 25°C shows close correspondence with the finding of Reinecke & Kriel (1980) of 26 days. The mean number of offspring of 2,7 per cocoon which was found in this study shows close correspondence with the finding of Neuhauser, Hartenstein & Kaplan (1980) and indicates a potential offspring number of 350 per worm per year. From the above data it is thus clear that the compost worm *Eisenia fetida* has a relatively short life-cycle with a high reproductive rate.

The life-cycle of *Eisenia fetida* is shown diagrammatically in Figure 6. Cocoon formation starts within four days of mating, and can be sustained for longer than 500

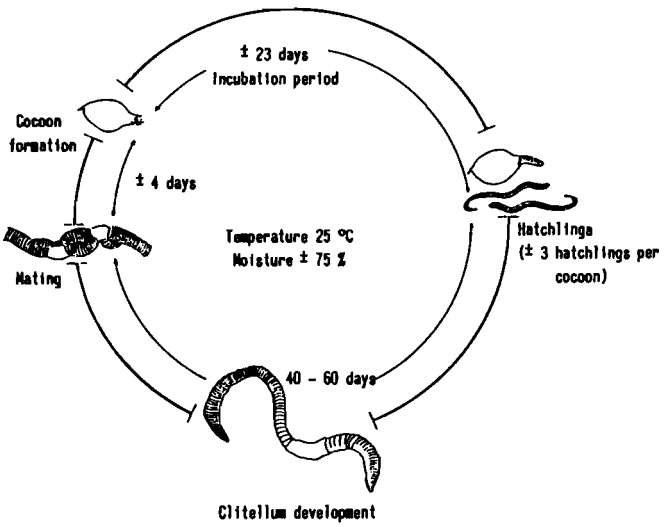

Figure 6 A diagram of the life cycle of *E. fetida* reared in cow manure at a temperature of 25°C and a moisture content of 75%.

days. Cocoons are produced at an average rate of 0,35 cocoons per day. The mean incubation period of cocoons at 25°C is 23 days, and an average of 2,7 offspring per cocoon are produced. Under favourable conditions the offspring will attain sexual maturity within 40 to 60 days after hatching, and will begin to mate.

Should the reproductive ability of *Eisenia fetida* be compared with that of other compost-inhabiting earthworms such as *Eudrilus eugeniae, Pheretima hawayana* and *Perionyx excavatus,* it would appear that *Eisenia fetida* has a greater reproductive ability. This is confirmed by Loehr *et al.* (1984). This makes *Eisenia fetida* very suitable as waste decomposer and as potential source of protein. However, to get accurate knowledge of the full potential of the compost worm as potential source of protein and as waste processor, it is essential that the life- cycle of the worm on every specific source of waste be studied thoroughly.

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