Influence of temperature on the reproduction of the earthworm *Eisenia foetida* (Oligochaeta)

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An experimental investigation revealed that cocoon production by *E. foetida* (Oligochaeta) increased linearly with increase in temperature in the range 10 to 25 °C. Diurnally fluctuating temperature did not have a marked influence on total cocoon production at the temperature levels of 10, 15 and 25 °C. A highly significant difference in cocoon production occurred between a constant temperature of 20 °C and a mean temperature of 20 °C (which fluctuated diurnally between 12 and 28 °C). Maximum cocoon production was obtained at 25 °C with each worm producing a cocoon every second day. The investigation also showed that temperature does influence the number of hatchlings per cocoon. At a temperature of 25 °C fewer worms hatched per cocoon than at 20 °C.

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'n Eksperimentele ondersoek het aan die lig gebring dat die kokonproduksie van *E. foetida* (Oligochaeta) lineêr toeneem met 'n toename in temperatuur binne die omvang van 10 tot 25 °C. Etmalige fluktuerende temperature het geen beduidende invloed op totale kokonproduksie by die temperatuurvlakke van 10, 15 en 25 °C gehad nie. 'n Hoogs betekenisvolle verskil het egter voorgekom tussen kokonproduksie by 'n konstante temperatuur van 20 °C en dié by 'n gemiddelde temperatuur van 20 °C (wat etmalig fluktueer tussen 12 en 28 °C). Maksimale kokonproduksie by 25 °C het beteken dat elke wurm elke tweede dag 'n kokon geproduseer het. Die ondersoek het ook aan die lig gebring dat temperatuur die getal nakomelinge per kokon kan beïnvloed en dat minder wurms by 25 °C as by 20 °C per kokon uitbroei.

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Some earthworm species have a potential as organic waste decomposers, according to various authors (Hartenstein, Neuhauser & Kaplan 1979a). Vermiculturists and researchers are attempting to utilize these earthworms on a much wider scale than before to decompose industrial organic waste materials such as pulp, sewage sludge, municipal refuse and agricultural wastes as well as animal manures from dairies and other livestock facilities (Huhta, Ikonen & Vilkamaa 1979). Earthworms are also cultivated for other reasons such as fishing and feeding supplements for poultry, fish and other livestock (Schulz & Graff 1977, Sabine 1978).

All of these practices require a fundamental knowledge of earthworm reproduction. Our knowledge of the biology of earthworms is far from complete. Only scattered data are available on their bionomics — an understanding of which is a prerequisite for their successful breeding and utilization.

Of the many different earthworm species only a few are utilized commercially. Attention has been focused recently on the use of *Eisenia foetida* (Savigny) for accelerating the decomposition of biodegradable wastes (Graff 1974, Watanabe & Tsukamoto 1976, Hartenstein *et al.* 1979a) and also on *Eudrilus eugeniae* (Neuhauser, Kaplan & Hartenstein 1979). *Eisenia foetida* is known under various names in different parts of the world such as 'brandling worm, red worm, zebra worm, Kariba worm, red wigler'. This species is commonly found in places where large concentrations of organic matter are decaying. It is frequently collected from compost heaps and manure piles. The available data on the biology of this species are often contradictory. Figures given by Evans & McGuild (1948) suggest that a single *E. foetida* adult produces only 11 cocoons per year. These authors also observed a peak production of 3,8 cocoons per worm per week in August at 13 °C in experimental studies. Graff (1974) reported up to 3 cocoons per worm per week at 25 °C. *E. foetida* is the only earthworm known to produce more than one or two hatchlings from a single cocoon. Vail (1974) mentioned a mean of 2,6 and Evans & Guild (1948) found eight.

It is not easy to estimate the number of progeny an earthworm will produce in a year. Much depends on weather conditions, soil conditions, temperature and available food. To obtain an overall picture of the reproductive capacity of an earthworm such factors as population density, interspecific competition and the in-

fluence of ageing of the breeding stock cannot be neglected. Although earthworms are prodigious reproducers their rate of multiplication is not always as great as is often stated and their numbers do not expand geometrically as is often suggested by commercial breeders.

Although various authors have studied the reproduction of earthworms, none of them mention the influence of diurnally fluctuating temperatures on cocoon production, the incidence of hatching, number of hatchlings and incubation time (Evans 1947, Moment 1953, Nakamura 1973). Most of the available data from reproduction studies have been obtained at constant temperatures, not taking into account the possible influence of temperature fluctuations occurring under natural conditions.

It is of importance for vermiculturists to know at which temperatures to rear earthworms, produce cocoons and incubate them. The present study was undertaken to examine the influence of constant as well as diurnally fluctuating temperatures on cocoon production and the number of hatchlings per cocoon.

Methods

The experimental worms were collected from compost heaps. The worms were reared indoors in boxes containing a mixture of cow manure and soil. Temperature conditions fluctuated between 18 and 26 °C. A close check was kept on soil moisture conditions to keep them within favourable limits for earthworm survival.

Adult worms of approximately the same size (aged between 9 and 15 weeks) were used. Two each were placed in petri dishes containing equal amounts (5g) of washed cow manure. The cover glasses of all petri dishes were coated to prevent light from penetrating. The petri dishes were divided between various Conviron environmental control chambers. Chambers which are programmable for temperature, photoperiod and humidity were used to simulate the fluctuating soil conditions that occur in soils close to the laboratory. The following diurnal fluctuations were programmed: 7 ° to 11 °C with a mean of 10 °C (simulating winter conditions at 10 cm depth); 11° to 18 °C with a mean of 15 °C (simulating autumn conditions in May); 12 ° to 28 °C with a mean of 20 °C and 21 ° to 29 °C with a mean of 25 °C (simulating two summer conditions). Incubators were also used at constant temperatures of 10 °C, 15 °C, 20 °C and 25 °C. The contents of each petri dish were checked daily for cocoons, using a bench type magnifying glass.

Results

Cocoon production

Table 1 summarizes the results obtained after subjecting batches of 20 adult worms to different temperature conditions. It can be clearly seen that the highest production rate was obtained at a constant temperature of 25 °C where 194 cocoons were produced by 20 worms after only 20 days. This amounts to a mean of 9,7 cocoons per worm over the period or almost one cocoon per worm every second day. The lowest production rate was at the constant temperature of 10 °C. Here 20 worms produced only nine cocoons over a period of 24 days. Figure 1 represents the results graphically and clearly illustrates the higher production rates at the higher temperatures.

Table 1 The accumulated number of cocoons produced by batches of 20 worms (*Eisenia foetida*) each at various temperature levels

	Cocoon production (Accumulated)							
	10 °C		15 °C		20 °C		25 °C	
Days	const.	fluct.	const.	fluct.	const.	fluct.	const.	fluct.
2	–	–	1	0	14	4	11	8
4	2	1	3	3	26	10	32	28
6	–	–	10	7	36	16	55	46
8	4	2	19	13	42	20	81	64
10	–	–	25	18	56	26	105	88
12	5	6	31	22	78	32	129	108
14	–	–	34	30	82	38	148	128
16	7	8	38	33	86	44	167	147
18	–	–	44	34	100	49	181	165
20	8	11	–	46	106	54	194	187
22	–	–	–	47	118	60	–	–
24	9	13	–	49	130	66	–	–

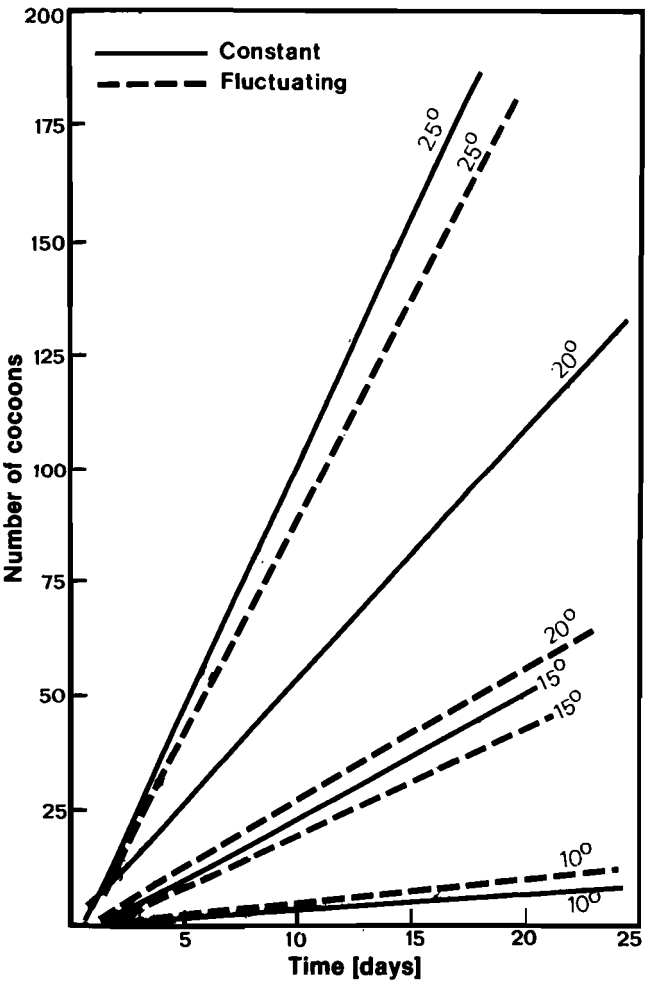

Fig. 1 The cocoon production and fluctuating temperatures of eight groups consisting of 20 earthworms each.

No significant difference occurred between the production rates at 10 °C (constant) and 10 °C (mean). The same holds true for 15 °C where only a slight difference in total cocoon production occurred. A very prominent, and statistically highly significant, difference occurred between the production rates and total yield at 20 °C (constant) and 20 °C (mean). More than double the number of cocoons were produced at a constant temperature of 20 °C as compared to production at the fluctuating level of 12 to 28 °C (mean 20 °C). At 25 °C the total cocoon production was again very similar at 25 °C (constant) and 25 °C (mean) although the production rate was slightly higher at the constant temperature during the first sixteen days.

Number of hatchlings per cocoon

The cocoons of *E. foetida* became transparent shortly before the worms started hatching. It was, however, impossible to count the number of worms before they hatched. The mass of fifty individual cocoons, incubated at a constant temperature of 25 °C, was determined and the number of hatchlings emerging from each cocoon was counted. No correlation was found between cocoon mass and the number of hatchlings. The masses of cocoons that produced the highest number of hatchlings were 13,4; 15,8; 18,0; 19,0 and 21,6 mg. Cocoons that produced only one hatchling had masses of 13,2; 14,5; 15,5; 16,3; 17,7; 17,8; 18,3 and 20,9 mg.

Table 2 contains a summary of the mean number of hatchlings per cocoon for the various production and incubation temperatures. This study revealed that temperature influences the number of hatchlings emerging from each cocoon.

Cocoons produced and incubated at 10 °C did not hatch for 230 days. Hatching occurred however 14 days later after these cocoons were subjected to a constant temperature of 25 °C. This finding clearly illustrates the ability of the cocoons to withstand unfavourable temperature conditions for prolonged periods of time.

Table 2 The number of hatchlings per cocoon at various temperatures (no hatchlings emerged at 10 °C after 230 days)

Temp °C						
Cocoon production	Cocoon incubation	No. of cocoons	% hatched	Mean no. of hatchlings	Variance	SE
15°	const.	50	90	2,6	0,98	0,15
const.	fluct.	50	92	2,7	0,95	0,14
15°	const.	50	90	2,3	0,95	0,15
fluct.	fluct.	50	90	2,4	0,75	0,13
20°	const.	50	96	3,1	0,96	0,14
const.	fluct.	50	100	3,2	1,31	0,16
20°	const.	50	92	2,1	10,74	0,13
fluct.	fluct.	50	96	2,6	0,75	0,13
25°	const.	50	92	2,4	1,41	0,18
const.	fluct.	50	96	2,7	0,90	0,14
25°	const.	50	92	2,2	0,65	0,12
fluct.	fluct.	50	98	2,8	1,10	0,15

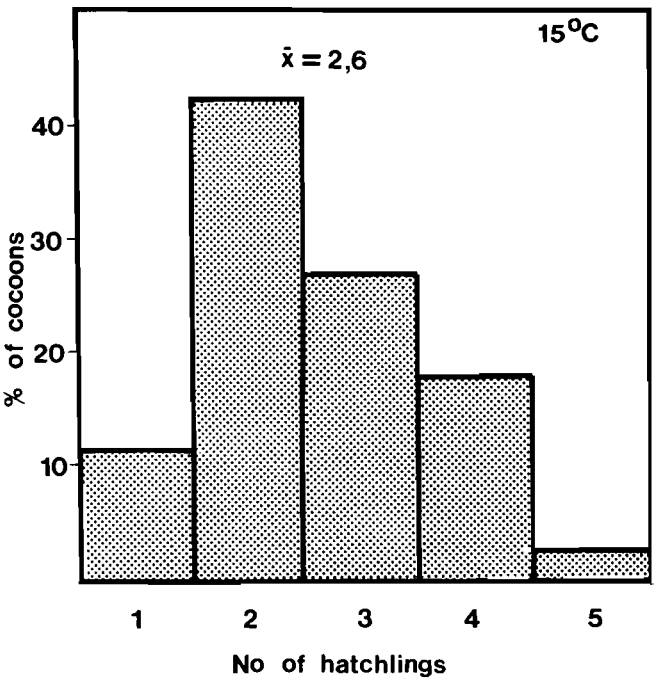

Fig. 2 The number of hatchlings per cocoon produced and incubated at 15 °C (constant).

At a constant incubation temperature of 15 °C only 11,1% of the cocoons produced one worm each while 42,2% of the cocoons produced two worms each. The mean production was 2,6 hatchlings per cocoon (Figure 2). At the fluctuating temperature of 15 °C the results were similar.

Cocoons produced at a constant temperature of 20 °C and incubated at the same temperature produced a mean of 3,1 hatchlings per cocoon. This result differed significantly (5% level) from the results obtained at 15 °C. Twenty cocoons (42%) produced three hatchlings and twelve (25%) produced four hatchlings (see Figure 3).

Cocoons incubated at a fluctuating temperature of 20 °C gave the same results with a mean of 3,2 hatchlings per cocoon. Cocoons produced at a fluctuating temperature of 20 °C and incubated at a constant temperature of 20 °C produced a mean of 2,1 hatchlings per cocoon. There was a difference between the number of hatchlings of cocoons produced at a constant temperature of 20 °C and those produced at the fluctuating temperature of 20 °C. The difference however was not statistically significant. On the basis of the number of hatchlings produced per cocoon a production and incubation temperature of 20 °C seems to be more favourable for reproduction than one of 15 °C.

Cocoons produced at a constant temperature of 25 °C and incubated at the same fluctuating temperature produced 2,4 hatchlings per cocoon. Cocoons incubated at a constant temperature of 25 °C produced 2,7 hatchlings per cocoon. Cocoons produced at a fluctuating temperature of 25 °C and incubated at a fluctuating temperature of 25 °C produced a mean of 2,8 hatchlings per cocoon. Cocoons produced at the fluctuating temperature of 25 °C and incubated at a constant temperature of 25 °C produced a mean of 2,2 hatchlings

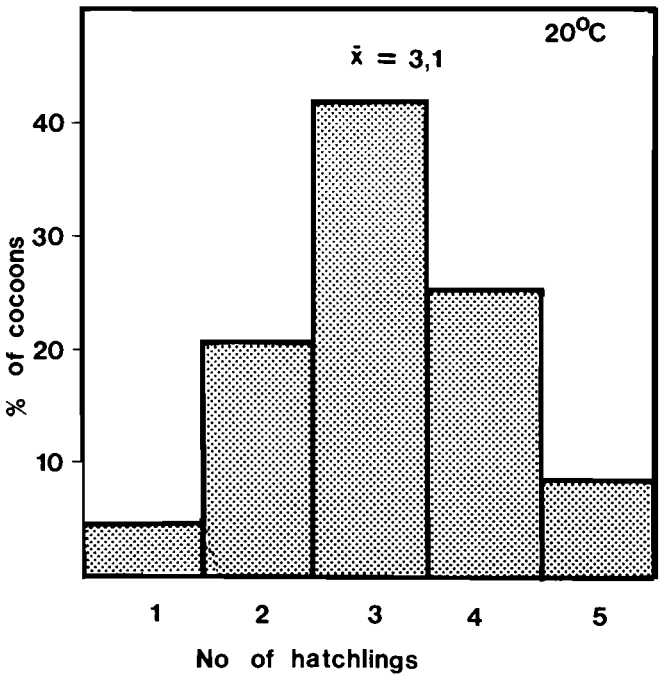

Fig. 3 The number of hatchlings per cocoon produced and incubated at 20 °C (constant).

per cocoon. The former number of hatchlings per cocoon differed significantly from the latter as well as from those obtained at 20 °C.

Discussion

In nature the production of cocoons by *E. foetida* seems to continue throughout the year. The magnitude however, differs from season to season and is highly dependent on environmental conditions. Pilot experiments undertaken during the present study revealed that cocoon production is not noticeably affected by change in soil moisture conditions within fairly wide limits. It is only when adverse conditions set in that cocoon production is affected. Temperature seems to play a much more important role in cocoon production as is clearly revealed by the present study. Results from field work indicate that the highest cocoon production is during spring and summer (Watanabe & Tsukamoto 1976).

From the present study it is quite clear that the highest yield of cocoons is obtained at 25 °C. Taking into account the fact that the temperature preferendum for *E. foetida* lies between 15,7 and 23,2 °C (Grant 1955) and also that a higher mean number of hatchlings might be obtained at a lower temperature level (Reinecke & Kriel 1980), the overall effect of 25 °C on reproduction (especially on hatchability of cocoons and incubation time) remains to be seen. Although a temperature level of 25 °C seems to favour cocoon production and to shorten the incubation period (Tsukamoto & Watanabe 1977) it might still not be the optimum temperature for rearing *E. foetida*.

The present study revealed a marked difference between 20 °C (constant) and a mean temperature of 20 °C fluctuating diurnally between 12 and 28 °C (which simulated autumn conditions in the soil). A breeding stock kept under natural conditions of seasonally and diurnally fluctuating temperatures will therefore produce far fewer cocoons. Earthworm breeders should keep in mind that most scientific literature generally refers to laboratory conditions where temperatures are fairly constant. Extrapolating these results to field conditions, as non-scientific literature so often does, can be very misleading.

The number of cocoons produced per adult *E. foetida* is also influenced by nutrition, age and population density (Hartenstein, Neuhauser & Kaplan 1979b). Peak production was found by the latter authors to occur between the ages of 9 to 11 weeks.

Although adult worms of approximately the same size class were used during the present production study, no attempt was made to do exact biomass determinations. Hartenstein, *et al.* (1979b) did find a significance for linearity of the regression of weight (biomass) of adult to weight of cocoon ($p<0,0001$) but they did not find conclusive evidence to predict progeny per cocoon in relation to weight of adult. The relation between worm size and cocoon numbers produced has not yet been studied although this will probably correspond to some extent to age distribution.

The present study on the number of hatchlings per cocoon showed that 20 °C was the most favourable temperature for producing and incubating cocoons to obtain the highest number of hatchlings per cocoon. A temperature of 25 °C which favours cocoon production, clearly resulted in fewer hatchlings emerging from each cocoon. This could be the result of fewer eggs being fertilized in the cocoon under these conditions. The cocoon production was however, significantly higher at 25 °C than at 20 °C. To obtain the highest yield a production and incubation temperature of 25 °C, which would also shorten the incubation period, should therefore be maintained in spite of the fact that slightly more worms could be produced per individual cocoon at a temperature of 20 °C.

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