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Effect of coffee residues on growth and reproduction of *Hyperiodrilus africanus* (Oligochaeta, Eudrilidae) in Ivory Coast

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Abstract *Hyperiodrilus africanus* (Beddard) is a 12-cm to 16-cm-long earthworm, which is widely distributed in West and Central Africa. It lives in the upper 10–20 cm of the soil, and feeds on a mixture of soil and above-ground litter. Cocoons obtained in the laboratory hatched on average 17 days after deposition and produced two juveniles on average. Paired individuals fed soil amended with 2% coffee residues grew significantly ($P < 0.05$) faster than those in the control soil. Daily individual weight increments were respectively 6.1 mg worm^{-1} day^{-1} and 1.0 mg worm^{-1} day^{-1} in supplemented and control soil. The generation time was short, and cocoon production reached 9.6 month^{-1} (i.e. 115 cocoons adult^{-1} year^{-1}). When *H. africanus* collected from the field were raised in the laboratory, they grew slowly, laid fewer cocoons and mortality was high. Demographic parameters indicated an improvement when *H. africanus* were raised in batches rather than individually. Mating enhanced cocoon production although parthenogenesis was possible.

Key words *H. africanus* · Earthworm growth · Cocoon production · Coffee residues

Introduction

After the role of earthworms in improving soil fertility in tropical soil was established (Lavelle et al. 1989; Spain et al. 1992), the search for the species most suitable and amenable to manipulation began. The widespread African earthworm *Hyperiodrilus africanus* has been identified by Barois et al. (1993) as one of the broadly distributed species that withstand disturbances linked to agricultural practices. This worm is found throughout West Africa (Ivory Coast, Nigeria) and Central Africa (Congo, Zaire and Angola) in disturbed and undisturbed areas (Omodeo 1954; Madge 1969; Lavelle, unpublished data; Tondoh, unpublished data). Populations concentrate in the upper 10–20 cm of soil and feed on a mixture of soil and above-ground litter. Individuals are frequently observed at the surface, especially, although not exclusively, during rainfall. Their role in the burial and further decomposition of litter, in combination with other species including *Eudrilus eugeniae*, has been stressed in a few papers (Hauser 1993; Tian 1995). Unlike the latter species, which has been thoroughly studied due to its importance in vermicomposting (Reinecke and Viljoen 1988; Viljoen and Reinecke 1989), the basic biology and demographic parameters of *H. africanus* have never been studied, with the exception of a preliminary study on field and laboratory activities by Madge (1969).

In order to fill this gap in knowledge of a species with high potential in agricultural practices (Barois et al. 1993), field and laboratory studies have been undertaken at Lamto, Ivory Coast, in an area of savanna that has been protected from fire for 32 years and further turned into a *Chromolaena odorata* fallow. The potential use of *H. africanus* in management of soil fertility depends, among other factors, on its growth and reproductive rates and its ability to produce a large number of individuals under field or laboratory conditions.

This paper assesses general demographic parameters (growth rate, generation time and fecundity) of *H. africanus* measured in laboratory cultures and the effects of their density on these demographic parameters. Coffee residues supplied as a pulp were used as food because they are available in most humid farming systems of Ivory Coast and are known to be suitable food for the geophagous earthworm *M. anomala* (Rousseaux 1994) and the epigeic earthworm *Eisenia fetida* (Orozco et al. 1996).

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Materials and methods

Description of *H. africanus*

H. africanus is a 12-cm to 16-cm-long epiendogeic earthworm that lives in the upper 10–20 cm of soil, and feeds on a mixture of soil and above-ground litter. It is slightly pigmented on its anterior body.

Study site

The study was conducted at the Lamto Tropical Ecology Research Station (5°02′W, 6°13′N) situated in the southern part of the Guinean savanna that penetrates the destroyed rain forest area of southern Ivory Coast. The research station is surrounded by a natural reserve of 2500 ha. The natural vegetation is characterized by a mosaic of grass savanna, shrub savanna and gallery forests.

A portion of the shrub savanna protected from fire since 1964 has turned into a secondary forest with significant undergrowth of the tropical weed *C. odorata*. In the Lamto area, *H. africanus* is only found in the portion of shrub savanna protected from fire and in coconut plantations close to the Bandama River. *H. africanus* was first recorded in 1978, and was probably introduced with ornamental trees in a garden near the protected savanna. The soil is a sandy ferrasol (FAO-UNESCO 1989).

Chemical characteristics of coffee residues

Coffee residues have high total organic carbon (30.4%) and soluble carbon (24 mg g^{-1}) contents (Table 1). Their polyphenolic concentration is low (0.44%). The polyphenolic/nitrogen (N) ratio (0.22) is inferior to 0.5, a critical value that determines the quality of plant material in terms of decomposition (Palm and Sanchez 1991). Coffee residues may therefore be considered as a good organic material for the provision of N as it can decompose to provide a readily available source of N in the short-term.

Experiments

Cocoons produced by adults of *H. africanus* were collected in the protected savanna close to the research station. They were kept in buckets filled with 9 kg moist soil (14% water content, i.e. pF 2.0 or 10 kPa) supplemented with 2 mm sieved coffee residues. A rate of 2% coffee residues was used since Tondoh and Lavelle (1997) showed that it is a suitable concentration for use in demographic studies. Every 5 days, the culture medium was changed, earthworms were handsorted and cocoons were collected by wet-sieving. After being weighed individually, cocoons were incubated on moist filter paper at 28°C in Petri dishes to assess incubation period and hatching rate.

Table 1 Chemical components of coffee residues. Polyphenols were extracted by Folin-Ciocalteu's method (Marigo 1973) and lignin by AFNOR XC 104.X.9003 method (Van Soest and Wine 1967). Soluble carbon was determined by a colorimetric method (Jirka and Carter 1975)

Dry matter (%)	90.60
Carbon (%)	30.40
Nitrogen (%)	2.01
C/N ratio	15.10
Soluble carbon (mg g^{-1})	24.00
Phosphorus (%)	0.16
Calcium (%)	0.69
Potassium (%)	1.93
Magnesium (%)	0.20
Aluminium (%)	0.62
Lignin (%)	22.20
Polyphenols (%)	0.44

Newly hatched individuals were kept in soil moistened at field capacity (14%, pF 2.0), which was either supplemented with 2% sieved coffee residues or left unaltered. Sixty worms hatched from 30 cocoons were divided into pairs and one of each pair was allocated to each treatment in plastic boxes filled up with 100 g substrate. Every 5 days during 325 days, worms were individually weighed and checked for clitellum development and cocoons were searched for, before worms were placed in a new medium. When worms reached a weight of approximately 200 mg, larger boxes containing 300 g substrate were used. Cocoons produced were weighed and kept for incubation.

A second set of experiments was conducted under similar conditions to evaluate the effects of *H. africanus* density on growth, maturation and cocoon production. Juveniles of *H. africanus* collected from the field were reared in boxes filled with 300 g soil amended with 2% coffee residues. Three treatments were set up with the boxes of each receiving, respectively, one, two and four earthworms. Ten replicates were set up for each density of earthworms. Dead worms were removed when renewing each medium.

Statistical tests

A non-parametric Mann-Whitney test was performed to compare the difference between growth and cocoon production of *H. africanus* in soil supplemented with 2% coffee residues and non-supplemented soil. The effects of *H. africanus* density on growth and cocoon production were analyzed using the Kruskall-Wallis test (Sokal and Rohlf 1995).

Results

Life-cycle of *H. africanus*

Cocoon size

Cocoons of *H. africanus* are oval. Specimens measured were, on average, 2.37 ± 0.03 mm (mean ± SE, $n = 106$) and weighed 15–58 mg (28 ± 0.21, $n = 1341$).

Incubation period of cocoons

Hatching of the first set of cocoons occurred after 10–32 days (17 ± 0.2 days). Cocoons further produced in the cultures hatched after 8–35 days (17 ± 0.03 days). Most cocoons (67% for the first set and 81% for the second) hatched between days 14 and 19 (Fig. 1).

Hatching success

Hatching success under laboratory conditions was, respectively, 71% in the first set of cocoons and 62% in the second set. Cocoons contained 2.1 ± 0.07 and 2.0 ± 0.04 individuals in the first and second generations. Fifty-four percent and 41% of cocoons of the first and the second generations, respectively, contained two embryos. A few cocoons contained up to five hatchlings (Table 2). Hatching may last several days since all individuals do not leave the cocoon at the same time.

Table 2 Number of hatchlings per cocoon of *Hyperiodrilus africanus*

Number of hatchlings per cocoon	First set		Second set	
	Number of cocoons	%	Number of cocoons	%
1	25	21.4	185	33.6
2	63	53.8	226	41.1
3	25	21.4	102	18.5
4	4	3.4	35	6.4
5	–	–	2	0.4
Total	117	100	500	100

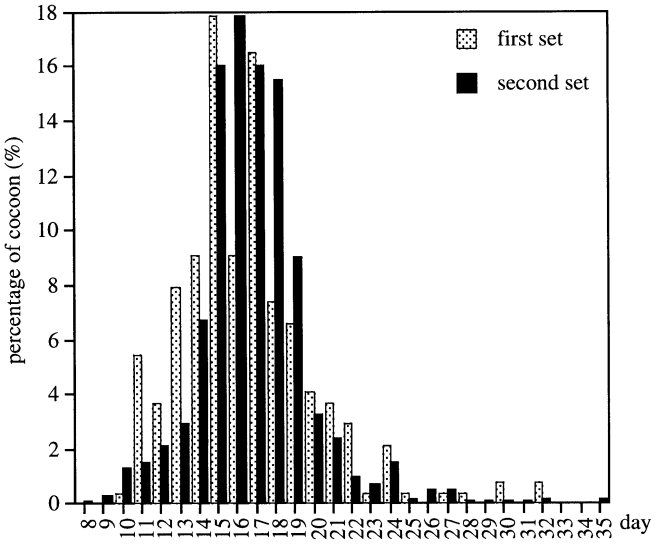

Fig. 1 Incubation time of cocoons of *Hyperiodrilus africanus*

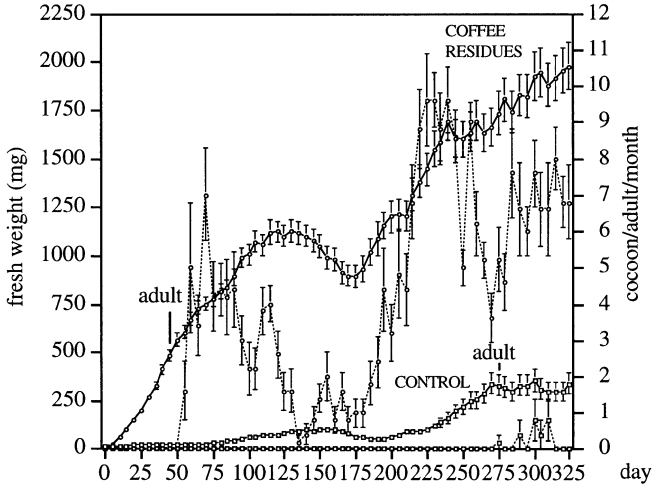

Fig. 2 Growth curves and cocoon production of paired *H. africanus* raised in soil enriched with 2% coffee residues and in the control

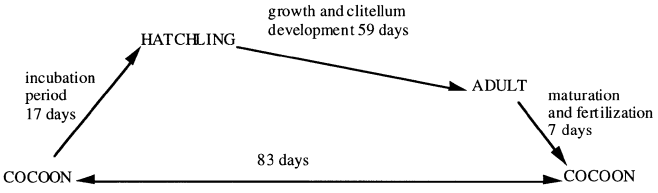

Fig. 3 Diagram of the life-cycle of the earthworm *H. africanus* in soil amended with 2% coffee residues

Growth

The weight of newly hatched worms ranged from 1 mg to 42 mg with a mean of 12.3 ± 0.2 mg. When fed soil mixed with 2% coffee residues, *H. africanus* grew at a rate of 6.1 mg worm^{-1} day^{-1}, and the first adult appeared on day 45 (Fig. 2). The growth of individuals was continuous throughout, although it declined between days 125 and 175. The mortality rate was 3.3% at the end of the experiment. All *H. africanus* individuals had become adults after 75 days. In soil without coffee residues, the worms grew very slowly (1.0 mg worm^{-1} day^{-1}; Fig. 2) and the growth time until formation of the clitellum was long (283 ± 3 days). After 275 days, one individual weighing 670 mg was clittelate. Mortality was 56.7% at the end of the experiment. A Mann-Whitney test showed significant differences in growth of *H. africanus* in both treatments ($P < 0.05$).

Cocoon production

Cocoon production began after 55 days, but was still irregular with respect to time (0.9 to 9.6 cocoons adult^{-1} month^{-1}) for *H. africanus* raised in soil amended with 2% coffee residues (Fig. 2). Although *H. africanus* laid cocoons continuously, three successive peaks were observed. The generation time was about 300 ± 7 days and fecundity was very low (0.3–0.9 cocoon adult^{-1} month^{-1}) in non-amended soil. The fecundity of *H. africanus* in both treatments differed significantly ($P < 0.05$).

The complete life-cycle of *H. africanus* was achieved under laboratory conditions within a period of 83 days. The average growth and generation times were 59 ± 2 and 66 ± 3 days in soil enriched with 2% coffee residues (Fig. 3).

Density-dependent effects

Growth

The growth of *H. africanus* raised either individually, in pairs or in batches of four individuals was significantly different at every stage when compared by the Kruskall-

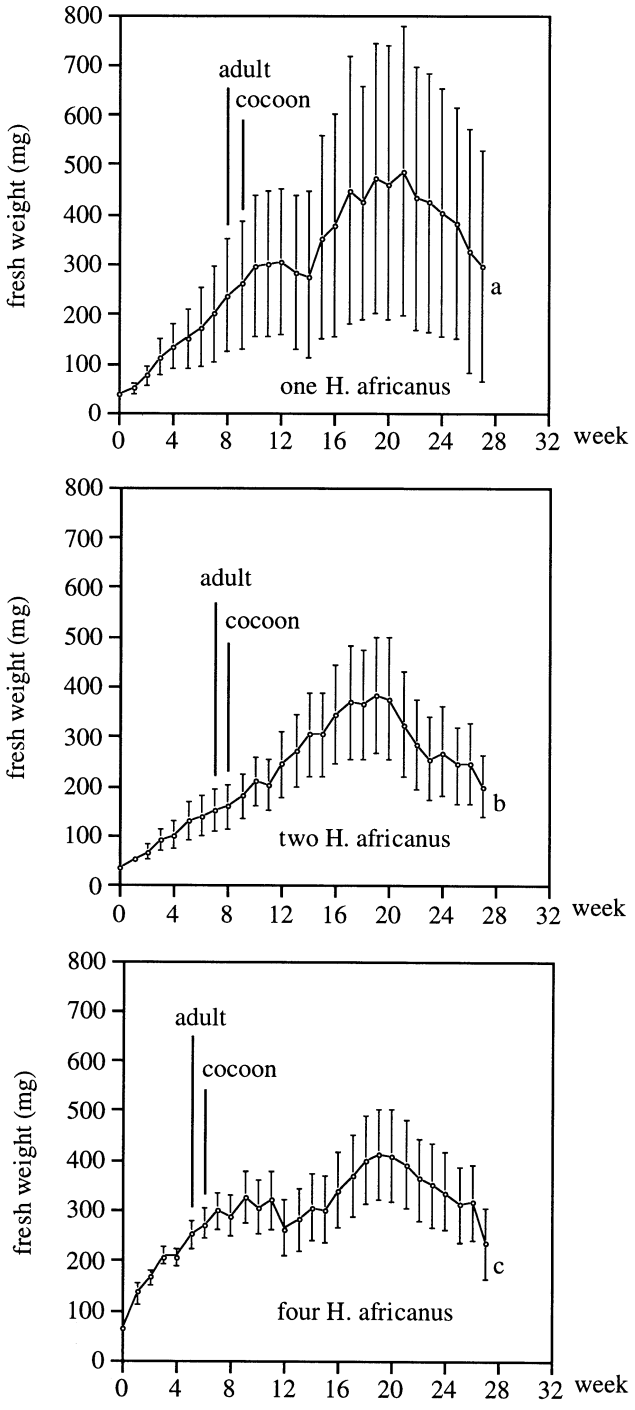

Fig. 4 Growth of *H. africanus* raised individually and in groups of two and four individuals in soil amended with 2% coffee residues

Wallis test ($P<0.05$). The largest weight was achieved by earthworms raised individually. The maximum weights were, respectively, 482.9 ± 289.8 mg, 382.1 ± 117.4 mg and 409.8 ± 92 mg and were reached within a period of 19–21 weeks (Fig. 4). Mortality was high among *H. africanus* raised individually (up to 80% at the end of the experiment), whereas only 55% of earthworms had died by the end of the experiment in the two other treatments. Growth rates were, respectively, 1.4 mg worm^{-1} day^{-1}, 0.9 mg worm^{-1} day^{-1} and 0.9 mg worm^{-1} day^{-1} in boxes containing one, two and four *H. africanus*, and it took, respectively, 56 ± 0 days, 70 ± 2 days and 49 ± 1 days for the worms to exhibit a clitellum.

Cocoon production

Cocoon production began a week after the appearance of clitellate individuals. When *H. africanus* was raised in batches, cocoon production was high. Groups of four *H. africanus* produced, in total, 172 cocoons in 154 days, and paired individuals produced 83 cocoons in 147 days. Fourteen cocoons were produced by earthworms raised individually in a shorter time period, i.e. 77 days. When expressed in terms of cocoons laid per adult per month, the average fecundity of worms raised individually (0.4–0.9 cocoon adult^{-1} month^{-1}) was significantly different ($P<0.05$) compared to that of individuals raised in pairs or kept in batches (0.1–3 cocoons adult^{-1}month^{-1}).

Discussion

H. africanus grew and reproduced faster when fed a soil supplemented with coffee residues. Tondoh and Lavelle (1997) indicated similar results for single *H. africanus* that grew slowly (2.9 mg worm^{-1} day^{-1}) in comparable conditions. The high amount of soluble carbon and organic phosphorus in coffee residues certainly stimulates growth. The generation time (2.2 months) was short and fecundity was high (up to 115 cocoons adult^{-1} year^{-1}). In contrast, Lamto native earthworm species (*Millsonia anomala*, *Dichogaster agilis*, *Millsonia ghanensis*, *Agastrodrilus opisthogynus*, *Millsonia lamtoiana* and *Chuniodrilus zielae*) have longer generation times (15–45 months) and cocoon incubation (23–36 days) and low fecundity (1–18 cocoons adult^{-1} year^{-1}) (Lavelle 1978). The incubation period of cocoons of the vermicomposting earthworm *E. eugeniae* (17 days) is similar to that of *H. africanus* (Reinecke and Viljoen 1988).

The demography of *H. africanus* indicates that it is more useful for large-scale earthworm production than the peregrine earthworm *Pontoscolex corethrurus* that has a longer generation time (4 months) and slightly lower fecundity (99 cocoons adult^{-1} year^{-1}) (Lavelle et al. 1987). The three peaks delimited during cocoon production of *H. africanus* probably show the presence of reproduction periods in the life-cycle.

The hatching success of 95% for the endogeic worm *M. anomala*, and 90.5% for the epigeic *D. agilis* (Lavelle 1978) were greater than that of *H. africanus*, i.e. 71%. Reinecke and Viljoen (1988) using the same medium (moist filter paper) found that *E. eugeniae* had a low hatching success of 48%. Compared to vermicomposting species, the 59 days of clitellum development in *H. africanus* is long. Reinecke and Hallat (1987) observed a clitellum in *Perionyx excavatus* after only 14 days, while Vil-

joen and Reinecke (1989) found the first clitellate *E. eugeniae* after 25 days.

H. africanus collected from the field and raised under laboratory conditions did not adapt very well. When kept in pairs, they grew very slowly (0.9 mg worm^{-1} day^{-1}), their fecundity was very low (up to 31 cocoons adult^{-1} year^{-1}) and mortality was high. The daily increment in weight of *H. africanus* collected from the field and raised individually (1.4 mg worm^{-1} day^{-1}) was inferior to the 3.2 mg worm^{-1} day^{-1} of *H. africanus* hatched in the laboratory and raised individually (Tondoh and Lavelle 1997). In addition, the former laid 11 cocoons year^{-1} in contrast to the 72 cocoons laid by laboratory hatchlings. It seems, therefore, that in order to obtain a high fecundity of *H. africanus*, production should start from individuals hatched in the laboratory.

The growth of *H. africanus* varies with their density. The better growth of *H. africanus* raised individually (1.5 times greater) clearly indicated the density dependence of this parameter. Space is probably the density-dependent factor, since food was not a limiting factor in our experiment. Reinecke and Viljoen (1993) recorded the same feature for *E. eugeniae* when the density was high. As a regulating factor of population size (Begon and Mortimer 1981), density dependence should be one of the factors regulating natural populations of *H. africanus*. Density dependence was also used as a regulating factor of a population of *M. anomala* in the model "Allez les Vers" (Lavelle and Meyer 1983). Although mating is not a prerequisite for cocoon production, fecundity was enhanced when individuals were in batches. Generally speaking, groups of two or four earthworms displayed better demographic parameters (high survival rate, short generation time and high fecundity), which explains the tendency of natural populations of *H. africanus* to aggregate as observed in the field (Tondoh, unpublished data).

The possibly parthenogenetic reproduction, fast maturation, high fecundity, high number of embryos (up to five) per cocoons and short generation time indicate that *H. africanus* populations have a high capacity for colonization. These demographic features may explain their large distribution in Africa. This species has potential for massive production and use in appropriate biotechnologies aimed at stimulating plant growth by promoting active earthworm populations.

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