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Effect of two organic residues on growth and cocoon production of the earthworm *Hyperiodrilus africanus* (Eudrilidae)

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Abstract

Growth and cocoon production by *Hyperiodrilus africanus*, a widespread epiendogeic earthworm of West and Central Africa were assessed in laboratory studies. The effects of coffee residues and *Chromolaena odorata* litter, organic residues commonly available in farming systems of Central Côte d'Ivoire, on these parameters were tested over 305 days. Addition of 0.5 and 2% coffee residues to the soil significantly increased growth of *H. africanus* in comparison to control (unamended soil) and addition of 4% coffee residues. In 0.5%, 2%, 4% coffee residue treatments and control, earthworm became adult within 90, 65, 250 and 300 days respectively. Fecundity varied from 3 to 6 cocoons adult^{-1} month^{-1} respectively for single earthworms and 2 to 5 for paired individuals in the 0.5% coffee treatment; 3 to 6 for single earthworms and 2 to 9 cocoons adult^{-1} month^{-1} for paired individuals in the 2% coffee treatment. In soil amended with *C. odorata* litter, *H. africanus* grew slowly and no individual reached the adult stage. Mortality was high.

Keywords: Earthworm, *Hyperiodrilus africanus*, organic input, growth, cocoon production.

Effets de deux résidus organiques sur la croissance et la production de cocons du ver de terre Hyperiodrilus africanus (*Eudrilidae*)

Résumé

La croissance et la production de cocons du ver de terre *Hyperiodrilus africanus*, un épiendogé largement répandu en Afrique occidentale et centrale ont été étudiées en conditions de laboratoire dans le but de connaître ses caractéristiques démographiques. L'effet des résidus (coques) de café et de litières de *Chromolaena odorata*, résidus organiques disponibles dans les systèmes de culture dans la partie centrale de la Côte d'Ivoire, sur ces paramètres a été testé pendant 305 jours.

La croissance d' *H. africanus* dans les sols enrichis avec 0.5 et 2% de résidus de café est significativement plus rapide que dans le sol témoin (sans amendement organique) ou dans le sol enrichi de 4% de résidus de café. Le stade adulte est atteint au bout de 90, 65 et 250 jours respectivement dans les traitements de 0.5%, 2% et 4% de résidus de café. Dans le sol témoin, *H. africanus* n'est adulte qu'au 300^{e} jour.

Dans les traitements de 0.5% de residus de café, la fécondité d'*H. africanus* varie de 3 à 6 cocons adulte^{-1} mois^{-1} pour les individus solitaires et 2 à 5 cocons adulte^{-1} mois^{-1} pour les individus appariés; dans les traitements de 2%, cette fécondité varie de 3 à 6 cocons adulte^{-1} mois^{-1} pour les individus solitaires et 2 à 9 cocons adulte^{-1} mois^{-1} pour les individus appariés .

Dans les sols enrichis de litière de *C. odorata*, *H. africanus* croît lentement; aucun individu n'est parvenu au stade adulte. La mortalité des vers est forte.

Mots-clés : Vers de terre, *Hyperiodrilus africanus*, amendement organique, croissance, production de cocon

1. INTRODUCTION

The earthworm *Hyperiodrilus africanus* (Beddard) is one of the few species that withstand disturbances linked to agricultural practices in tropical Africa (Barois *et al.*, 1993). This earthworm therefore presents a significant potential to improve or maintain soil fertility in systems that would integrate earthworm management as an additional practice. *H. africanus* is widespread throughout West (Côte d'Ivoire, Nigeria) and Central Africa (Congo, Democratic Republic of Congo, Angola) (Omodeo, 1954; Lavelle, unpubl. data). It is abundant in forest or periforest areas with annual rainfall in the range of 1300-1800 mm, and may also be found in savannas under drier conditions (e.g. Ouango Fitini in Northern Côte d'Ivoire with 1100 mm rainfall and 4 months dry season).

In Nigeria, *H. africanus* represents the most important earthworm population in agroforestery systems at Ibadan and comprises 45 to 86% of density and biomass (Tondoh, unpubl. data). Its role in plant residue decomposition and nutrient recycling has already been emphasised (Hauser, 1993; Tian, 1995). At Lamto (Central Côte d'Ivoire), an area dominated by guinean savannas, *H. africanus* is only found in areas that have been protected from fire since 1964 and in coconut plantations close to the river Bandama. Protection from fire has developed a facies of secondary forest with significant undergrowth of the tropical weed *Chromolaena odorata*.

One of the objectives of the Macrofauna (STD_3-EC funded) program has been to assess basic ecological traits of species with wide environmental tolerance and/or extended distribution. Studies were therefore carried out to determine growth and cocoon production by *H. africanus* in a control soil and soil amended with organic residues which might improve these parameters and facilitate field scale manipulation of populations. *C. odorata* litter and coffee residues were tested as food sources. *C. odorata* litter is common in the field where it is ingested with soil mixed by natural populations of *H. africanus*. Coffee residues, are widely available under most humid farming systems in Côte d'Ivoire and are known to be a suitable food for the geophagous earthworm *Millsonia anomala* (Rousseaux, 1994) and the compost earthworm *Eisenia fetida* (Orozco *et al.*, 1996).

Two hypotheses were tested in the present study:

- the dependence of *H. africanus* growth and reproduction on the avaibility of the above mentioned organic residues at different concentrations in soil,

- the existence of a parthenogenetic mode of reproduction in *H. africanus* already observed in most peregrine earthworm species.

2. MATERIALS AND METHODS

Site description

The study site is located in Côte d'Ivoire, 160 km north-west of Abidjan, in the Lamto natural reserve (5°02'W - 6°13'N). The area is situated in the southern part of the guinean savannas that penetrate the largely destroyed rain forest belt of Côte d'Ivoire. Adult specimen of *H. africanus* were collected in an area of savanna that had been protected from fire for 32 years. The vegetation was secondary forest regrowth with a dense undergrowth of the tropical weed *C. odorata*. The soil is a sandy ferralsol according to the FAO classification.

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

	coffee residues	*C. odorata* litter	control soil
dry matter	90.6	94.3	-
carbon (%)	30.4	17.8	1.2
nitrogen (%)	2.01	1.25	0.10
C/N ratio	15.1	14.2	11.7
soluble carbon (mgC.g^{-1})	24	12	-
phosphorus (%)	0.16	0.08	-
calcium (%)	0.69	0.93	-
potassium (%)	1.93	1.4	-
magnesium (%)	0.20	0.42	-
aluminium (%)	0.62	0.55	-
lignin (%)	22.2	15.3	-
polyphenols (%)	0.44	0.37	-

Experiments

Newly hatched specimens of *H. africanus* were raised singly in the laboratory at 28°C in small plastic boxes (9 × 6 × 2 cm) containing 100 g of 2mm-sieved soil from the upper 10 cm layer. *C. odorata* litter was collected at the soil surface and air- dried in the laboratory; coffee residues were collected from farmers. Soil was moistened to field capacity (14% water content *i.e.*, pF 2.0) and amended with 2 mm-sieved coffee residues or litter of *C. odorata*. Organic residues were mixed at rates of 0.5%, 2% or 4% to the soil. A control without organic residues was also used. Each treatment was replicated 10 times. When earthworms reached a weight of approximately 200 mg, larger boxes (16 × 9 × 7 cm) containing 300 g of substrate were used. After 140 days, surviving individuals were paired or kept singly to evaluate fecundity and test for parthenogenetic reproduction. Individuals were weighed every 5 days and each medium was renewed for another 165 days.

The chemical characterization of the organic residues and the control soil are given in *table 1*. Carbon concentration was twiced in coffee residues. Similar results were obtained on soluble carbon contents. The polyphenolic-to-N ratio of *C. odorata* litter (0.2) is not far from that of coffee residues (0.3) indicating their decomposibility. Palm and Sanchez (1991) showed that plant material with a low polyphenolic content or polyphenolic-to-N ratio (< 0.5) is a readily-available source of N.

Statistical tests

The effect of organic residues on growth of single specimens of *H. africanus* over 140 days were tested using the nonparametric test of Kruskall-Wallis (Sokal and Rolf, 1995).

The relationships between *H. africanus*, coffee residues and *C. odorata* litter mixed with soil were investigated with a standardized Principal Component Analysis (PCA) (Thioulouse, 1990, Webster and Oliver, 1990).

3. RESULTS

Addition of organic residues significantly accelerated growth in all cases. Maximum values of *H. africanus* weights (mean ± SE) were respectively 662.7 ± 98.8, 657 ± 123 and 187.9 ± 84.4 mg in soil supplemented with 0.5%, 2% and 4% coffee residues (*fig. 1*); 361.5 ± 49.1, 208.9 ± 41.2 and 142.1 ± 23.0 mg with *C. odorata* litter (*fig. 2*) and 65.6 ± 24.2 mg in the control. Respective daily individual weight increments were 3.2, 2.9 and 0.6 mg $worm^{-1}$ day^{-1} in the coffee treatments; 1.5, 0.3 and −0.1 mg $worm^{-1}$ day^{-1} with *C. odorata* litter and 0.4 mg $worm^{-1}$ day^{-1} in control soil. The first clitellate individuals were observed at days 90 and 65 in the 2% and 0.5% coffee residue treatments respectively and at days 250 in the 4% treatment and 300 in the control. The Kruskall-Wallis test did not show any significant ($p<0.05$) difference in *H. africanus* growth in soil amended with 0.5% and 2% coffee residues on the one hand, and 4% coffee residues and 2% *C. odorata* litter treatments on the other hand.

Only earthworms fed coffee residues produced cocoons. Single specimens of *H. africanus* were able to produce viable cocoons on days 125 in the 0.5% and 215 in the 2% treatment. Fecundity of single and paired specimens (2 to 6 cocoons $adult^{-1}$ $month^{-1}$) are similar in the 0.5% treatment. In the 2% coffee residue treatment, single and paired specimen of *H. africanus* produced (3 - 6 cocoons $adult^{-1}$ $month^{-1}$) and (2 - 9 cocoons $adult^{-1}$ $month^{-1}$). The number of surviving *H. africanus* decreased with increasing concentration of organic residues. In soil amended with coffee residues 7, 4 and 2 individuals survived for 305 days in the 0.5%, 2%, and 4% treatments respectively. In the *C. odorata* litter treatment only earthworms that had been fed on 0.5% litter survived (6) for 305 days. In 2% and 4% litter concentrations, all worms had died after 225 and 140 days. Five specimens of *H. africanus* survived in the control treatment.

Principal Component Analysis isolated two axes. The first axis (PC1) accounted for 70% of the total inertia. Along this axis, treatments with low organic residues (0.5%, 2%) were separated from treatments with high inputs of organic residues (4%). The second axis (PC2) with 22% of the total inertia, separated coffee residue from *C. odorata* litter treatments (*fig. 3*). The first factor (PC1) is related to the effects of organic residue concentrations in soil. Treatments with low (0.5%) and medium (2%) organic residue rates are separated from the 4% concentration. The second factor (PC2), explained the type of organic residues: coffee residues (high nutritive quality) are opposed to *C. odorata* litter (low nutritive quality). The correlation circle shows that soluble carbon and organic phosphorus are positively correlated with the generation time (Gt) and negatively with the fecundity (F2). Aluminium, magnesium and calcium are negatively correlated with growth (Gr) and survival rate (Sr) of *H. africanus* populations (*fig. 4*).

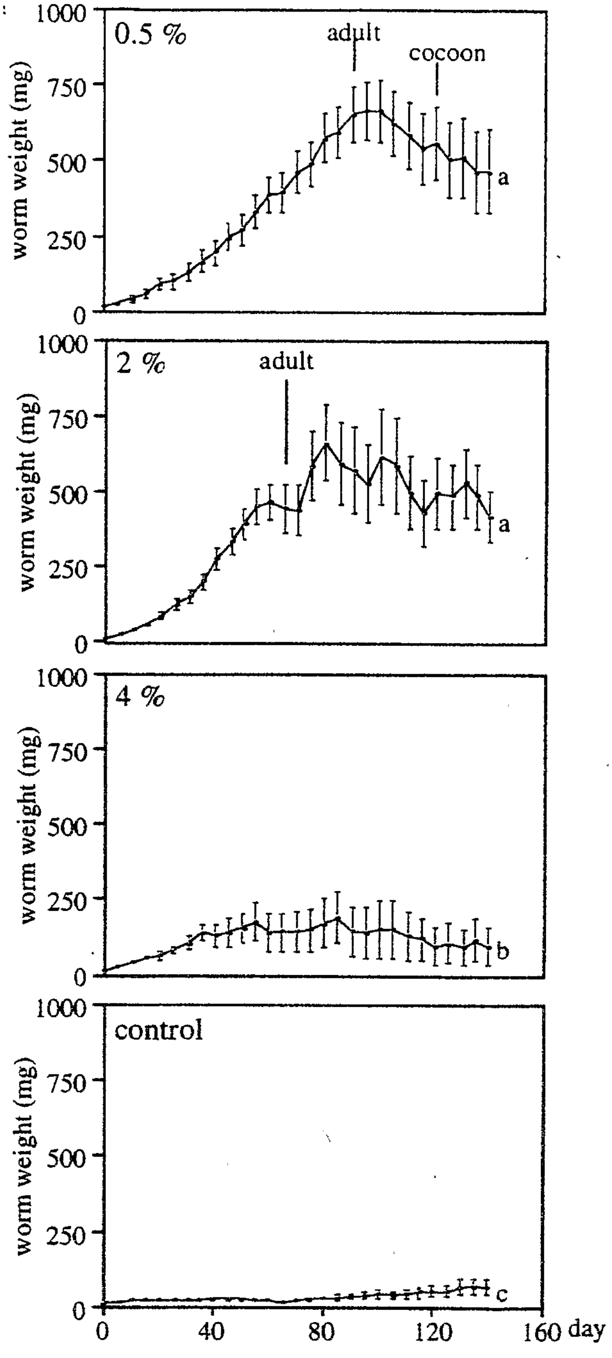

Figure 1. – Growth curves for *H. africanus* reared in soil amended with coffee residues at various concentrations. Treatments followed by the same letter do not differ significantly ($p<0.05$).

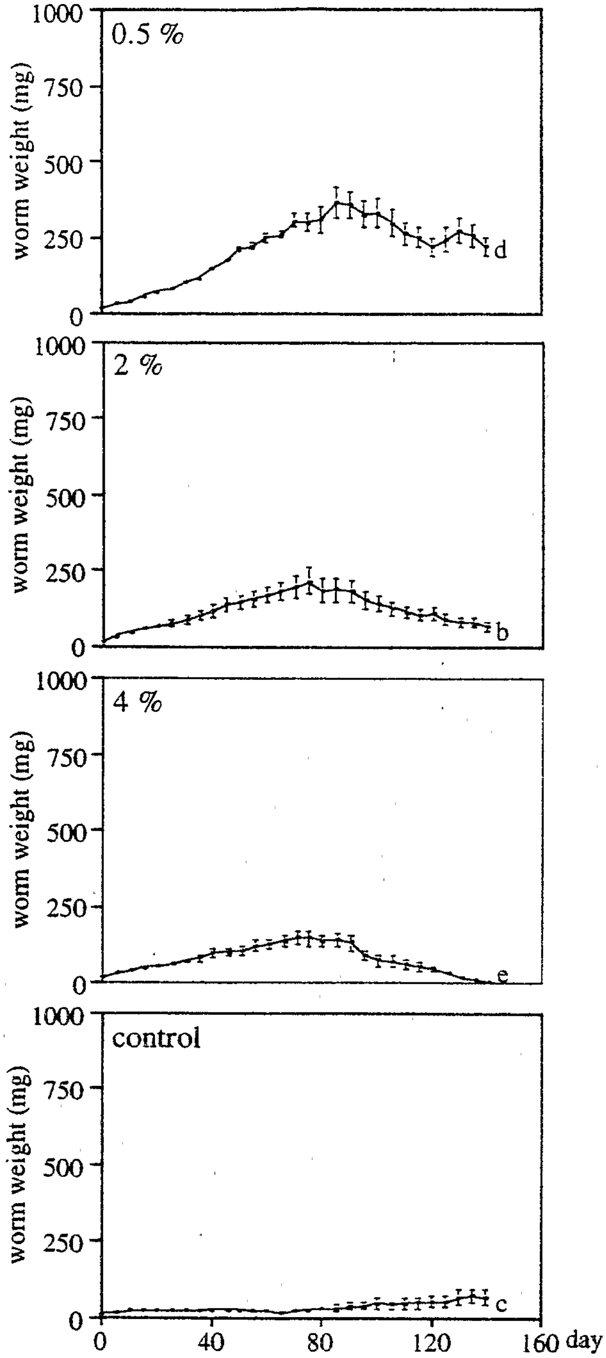

Figure 2. – Growth curves for *H. africanus* reared in soil amended with *C. odorata* litter at various concentrations. Treatments followed by the same letter do not differ significantly ($p<0.05$).

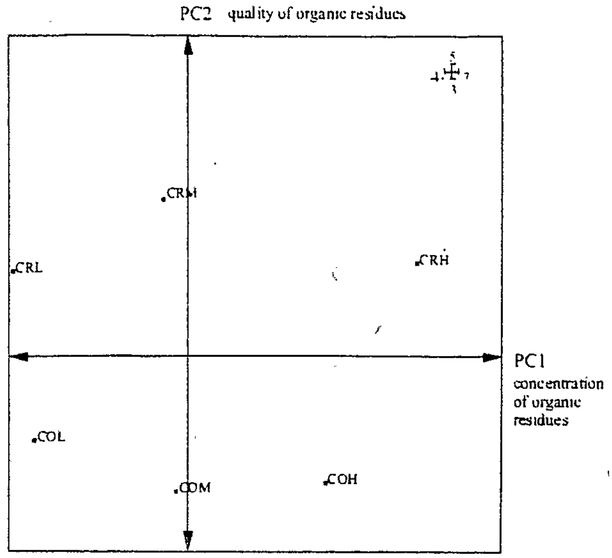

Figure 3. – Position of the different treatments in the plan defined by factorial axes. PC1 represents 70% of total inertia and PC2, 22%. CRL: 0.5% coffee residues CRM: 2% coffee residues CRH: 4% coffee residues. COL, COM and COH are respectively 0.5%, 2% and 4% *C. odorata* litter

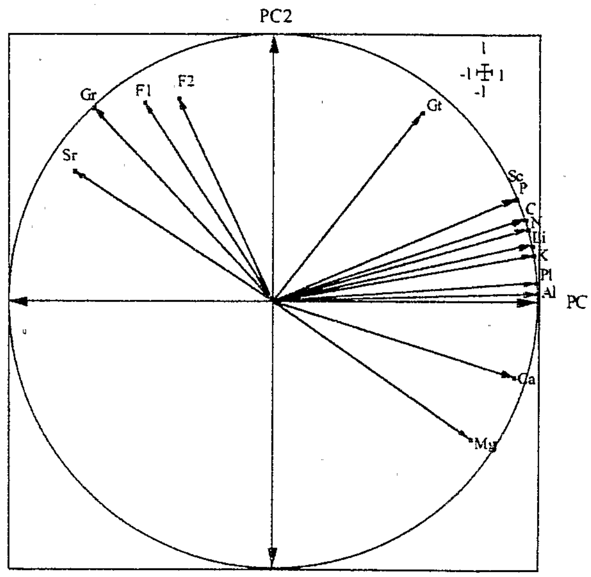

Figure 4. – Relationships between demographic parameters and different components of organic residues. C: carbon, N: nitrogen, SC: soluble carbon. P: phosphorus. Ca: calcium. K: potassium. Mg: magnesium. Al: aluminium. Li: lignin. Pl: polyphenol. F1: fecundity of single specimens of *H. africanus*. F2: fecundity of paired specimen of *H. africanus*. Sr: survival rate. Gr: growth rate and Gt: generation time

4. DISCUSSION

H. africanus was raised successfully under laboratory conditions, in contrast to many native species of the humid tropics that do not adapt to such a disturbance (Barois *et al.*, 1996). Therefore, large scale production of this species for field manipulation seems to be feasible. *H. africanus* showed markedly different reactions to different kinds and concentrations of organic residues with two and 0.5% being suitable concentrations for the development of this species. Principal Component Analysis distinguished two essential factors that may explain the response of *H. africanus* to organic amendments: the amount of the organic input and its nutritive quality. Coffee residues are of high nutritive quality and seem to be more suitable than *C. odorata* litter for the improvement of *H. africanus* growth and maturation. Similar results were recorded for the geophagous *M. anomala* after being fed soil enriched with 1% powdered leaves of *Loudetia simplex*, the dominant Graminea of grass savannas in Lamto and 1% coffee residues (Lavelle *et al.*, 1989; Rousseaux, 1994). The better response of *H. africanus* to low concentrations of coffee residues may be explained by higher contents of soluble carbon, phosphorus and nitrogen. Similar results have been obtained for *M. anomala* growth (Lavelle *et al.*, 1983; Lavelle *et al.*, 1989). Mortality increases with concentration of coffee residues and *C. odorata* litter. This result is in agreement with those obtained for *M. anomala* raised in soil amended with coffee residues (Rousseaux, 1994), and in soil supplemented with a graminean water-soluble extract (Lavelle *et al.*, 1983). A likely explanation is the development of fungal mycelium that causes earthworm mortality and aluminium at high rate. The short generation time of *H. africanus* in 0.5% (4 months) and in 2% (7 months) coffee residue treatments is similar to the 4 months of *Pontoscolex corethrurus* and the 9 months for *Polypheretima elongata* (Barois *et al.*, 1996). The fecundity equivalent to 108 cocoons adult^{-1} year^{-1} for paired *H. africanus* in 2% coffee residue treatment is almost similar or higher than that observed respectively for *P. corethrurus* (99 cocoons adult^{-1} year^{-1}) and *P. elongata* (45 cocoons adult^{-1} year^{-1}), both exotic species with large environmental tolerance (Lavelle *et al.*, 1987; Barois *et al.*, 1996). Fecundity and generation time of *H. africanus* contrast strongly with those of Lamto native species. Their fecundity (1 to 18 cocoons adult^{-1} year^{-1}) is very low and their generation time is in the range of 15 to 45 months (Lavelle, 1978). Mating does not seem to be a prerequisite for cocoon production by *H. africanus* in 0.5% and 2% coffee residue treatments since worms kept single produced cocoons. Similar observations were made for *P. corethrurus* and *P. elongata* (Barois *et al.*, 1996), *Eisenia fetida* (Venter & Reinecke, 1987) and *Perionyx excavatus* (Hallat *et al.*, 1990). No individual reached the adult stage in soil supplemented with the field litter of *C. odorata*. The failure of earthworm maturation in *C. odorata* litter treatment could be attributed to the quality of this litter. *C. odorata* litter collected from the field was already partly decomposed so that organic and soluble carbon contents were low.

H. africanus is an earthworm species that can be manipulated in low input agricultural systems to test its effect on the improvement or the conservation of soil fertility. This earthworm responds very well to the addition of coffee residues to soil. In addition, its demographic parameters (short time generation, high fecundity and possibly parthenogenetic reproduction) make it very comparable with the highly successful tropical peregrine species that have invaded disturbed soils worldwide.

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REFERENCES

Barois I. Kanyonyo J & Brown G. (1993). – Ecology of selected species. *In:* P. Lavelle (Ed.), *Conservation of soil fertility in low input agricultural systems of the humid tropics by manipulating earthworm communities. Macrofauna 2*, **1**, pp. 23-28.

Barois I., Angeles A. Blanchart E., Brossart M., Fragoso, C., Jimenez J. J., Martinez M. A., Moreno A., Lattaud C., Lavelle P., Rossi J. P., Senapati B. & Tondoh E. J. (1996). – Ecology of selected species with large environmental tolerance and/or extended distributions. *In:* P. Lavelle (Ed.), *Conservation of soil fertility in low input agricultural systems of the humid tropics by manipulating earthworm communities. Macrofauna 2*, STD3-EC final report, pp. 38-59.

Hallat L., Reinecke A. L. & Viljoen S. A. (1990). – Life cycle of the compost worm *Perionyx excavatus* (Oligochaeta). *S. Afr. J. Zool.*, **25**, 41-45.

Hauser S. (1993). – Distribution and activity of earthworms and contribution to nutrient recycling in alley cropping. *Biol. Fert. Soils*, **15**, 16-20.

Jirka A. M. & Carter M. J. (1975). – *Analytical Chemiestry*, **47**, 1397.

Lavelle P. (1978). – Les vers de terre de la savane de Lamto (Côte d'Ivoire) : peuplements, populations et fonction dans l'écosystème. Thèse de doctorat, Paris VI. Publi. Labo. Zool. ENS, 301 pp.

Lavelle P., Zaidi Z. & Schaefer R. (1983). – Interaction between earthworms, soil organic matter and soil microflora in an African savanna soil. *New Trend in Soil Biology*. Procedings of the VII. Intl Colloquium of soil Zoology, pp. 253-258.

Lavelle P., Barois I., Cruz I., Fragoso C., Hernandez A., Pineda A. & Rangel P. (1987). – Adaptative strategies of *Pontoscolex corethrurus* (Glossoscolecidae, Oligochaeta), a peregrine geophagous earthworm of the humid tropics. *Biol. Fertil. Soils*, **5**, 188-194.

Lavelle P., Schaefer R. & Zaidi Z. (1989). – Soil ingestion and growth in *Millsonia anomala*, a tropical earthworm, as influenced by the quality of the organic matter ingested. *Pedobiologia*, **33**, 379-388.

Marigo G. (1973). – Sur une méthode de fractionnement et d'estimation des composés phénoliques chez les végétaux. *Analysis*, **2**, 106-110.

Omodeo P. (1954). – Eudrilinae e octochaetinae delle Costa d'Ovorio (Oligochaeta). *Mem. Mus. civ. St. nat. Verona*, **IV**, 213-229.

Orozco F. H., Cegarra J., Trujillo L. M. & Roig A. (1996). – Vermicomposting of coffee pulp using the earthworm *Eisenia fetida*: Effect on C and N contents and the availability of nutrients. *Biol. Fertil. Soils*, **22**, 162-166.

Palm C. A. & Sanchez P. A. (1991). – Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. *Soil Biol. Biochem.*, **1**, 83-88.

Rousseaux L. (1994). – Valorisation agricole des résidus de recolte de café en association avec deux espèces de vers de terre dans la région de Lamto (Moyenne Côte d'Ivoire). Mémoire D.E.S.S. Université Paris XII, 57 pp.

Sokal R. R. & Rohlf F. J. (1995). – Biometry, Third Edition. W.H. Freeman and Company, New York, 887 pp.

Tian G. (1995). – Breakdown of plant residues with contrasting chemical compositions under humid tropical conditions: effets of earthworms and millipedes. *Soil Biol. Biochem.*, **27**, 277-280.

Thioulouse J. (1990). – Macmul and Graphmu: two Macintosh programs for the display and analysis of multivariate data. *Comp. Geosci.*, **16**, 1235-1240.

Van Soest P. J. & Wine R. H. (1967). – Use of detergents in the analysis of fibrous feeds. IV. Determination of plant cell-wall constituents. *J. Assoc. off. anal. Chem.*, **51**, 50-55

Venter J. M. & Reinecke A. J. (1987). – Can the commercial earthworm *Eisenia fetida* (Oligochaeta) reproduce parthenogenetically? *Rev. Ecol. Biol. Sol*, **24**, 157-170.

Webster R. & Oliver M. A. (1990). – Statistical methods in soil and land resource survey. Oxford University Press, New York, 316 pp.