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EFFECTS OF EARTHWORMS ON SOME SOIL PHYSICAL AND CHEMICAL PROPERTIES: THEIR POTENTIAL USE IN TROPICAL AGRICULTURE.

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ABSTACT

In the ecosystems of the humid tropics, earthworms are often the major component of soil macrofauna. In these systems, earthworm effects on physical and chemical soil properties are important. They affect soil porosity and structural stability as well as soil organic matter dynamics and nutrient release.

Land managements used in tropical areas lead to a dramatic decrease of both density and biomass of earthworms and at short term, soil degradation by overmineralization and erosion.

The management of earthworms in order to restore properties of soils degraded by successive crops or to sustain fertility of low-input agricultural systems is discussed.

Keywords: Earthworms, humid tropics, soil organic matter, soil aggregation

INTRODUCTION

It is now well established that most of the cultural practices used in the humid tropics lead to soil degradation. This degradation is due to (i) losses of nutrients with exported crops, (ii) losses of fine particles rich in organic matter by erosion of unprotected soils, (iii) overmineralization of SOM (soil organic matter), (iv) deterioration of soil structure and (v) decrease of biological activity. In low-input systems, the crop productions decrease rapidly after 2 or 3 years.

There is today an urgent necessity to find agricultural techniques that limit these effects and allow the conservation of SOM, the formation of stable soil aggregates, the formation of macropores that favour infiltration and limit the runoff (LAL, 1991).

Earthworms are often a major component of soil macrofauna in the natural systems of the humid tropics but they are absent or rare in cultivated fields (LAVELLE *et al.*, 1991 ; Lee, 1991). When present and active, they influence organic matter decomposition and nutrient cycling and affect soil structure and porosity (LAVELLE *et al.*, 1992a).

In agroecosystems, management of earthworm communities could be a way to i) improve yields and conserve soil fertility in low input systems and/or ii) restore degraded soils by example in increasing fallow efficiency.

This paper was aimed at presenting the main effects of earthworms on physical and chemical soil properties and present recent results in pot and field experiments in which earthworm effects on plant production were investigated.

EARTHWORMS IN NATURAL ECOSYSTEMS AND AGROECOSYSTEMS

In natural systems of the humid tropics, where annual rainfall are higher than 1,000 -1,100 mm, soil macrofauna is dominated by earthworms (LAVELLE *et al.*, 1991). Earthworm communities in forests and savannas can reach very high densities and biomasses (generally between 50 and 100 g.m^{-2}).

In cultivated soils, ploughing, tillage, application of biocides (especially nematicides and fungicides) and absence of plant cover are responsible for the low observed densities and biomasses (BARLEY, 1970 ; LOW, 1972 ; LAVELLE *et al.*, 1991).

In a recent study, Lavelle & Pashanasi (1989) showed clearly the impact of land management on earthworm biomass (Figure 1). In Peruvian Amazonia, deforestation and soil cultivation lead to a decrease of earthworm biomass whatever the cropping system is (high inputs, low inputs or traditional crops). When the cultivated soils are turned to

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pastures or fallows, opportunistic species rapidly recolonize the soil and reach high biomasses (up to 160 g.m^{-2}).

At Sainte Anne (Martinique), the population of *Polypheretima elongata* (Megascolecidae) shows density of ca. 3 ind.m^{-2} on average in market gardening plots (conventional tillage) and density reaches ca. 160 ind.m^{-2} on average with highest value of 345 ind.m^{-2} in a ten years old irrigated pasture previously used as high input system (Rossi, 1992). These results demonstrate the possible high recolonization by earthworms in degraded soils when cultural practices are stopped.

EFFECTS OF EARTHWORM ON SOIL PHYSICAL PROPERTIES

Earthworms are divided into three ecological categories : **epigeics** which inhabit and feed on litter, **anecics** which feed on litter but inhabit in the soil where they build vertical or sub-vertical burrows and **endogeics** which feed on SOM and inhabit the soil where they build horizontal or sub-horizontal burrows (Bouché, 1977). Earthworms of the last two classes egest a proportion of their casts (excrements) on the soil surface and a proportion in the galleries they dig.

Lavelle (1978) showed that, in the moist savannas of Lamto (Côte d'Ivoire), surface casts only represent 1.7 to 3.5% of the soil that passes through the gut of the endogeic earthworms. Almost all the ingested soil is excreted in the subsoil under the form of stable macroaggregates. Blanchart *et al.* (1990) showed that in this sandy soil of Lamto, such macroaggregates may comprise 50 to 60% of the soil. In a field experiment, this author showed that in a 2 mm-sieved soil, earthworms were responsible for the formation of a high proportion of soil as macroaggregates larger than 2 mm while the macroaggregates formed in absence of worms were very rare (Blanchart, 1992) (Figure 2). Macroaggregates produced in presence of earthworms were found to remain stable for a long time.

Cast deposition and burrowing activities result in the formation of stable macropores that favour water infiltration. Lal (1988) observed an increase of water infiltration rate in presence of active earthworms as compared to absence of earthworms. Aina (1984) also noticed such an effect. This author showed an increase of water infiltration rate with the natural recolonization of soil in both forest and in a long term

cultivation where earthworms were exterminated by application of pesticides and pre-existing channels destroyed by puddling. At Lamto, the activity of earthworms lead to an increase of both macro- and micropores at the expense of mesopores. The major consequence is a decrease of total porosity while the available water was increased (+ 10 to 14%) (Blanchart, in prep.).
Finally, earthworm channels, chambers and casts are considerated to favour root growth and to facilitate gaseous exhanges and transport of water and nutrients (Brussaard et al., 1993; Lal, 1988).

EFFECTS OF EARTHWORMS ON SOIL ORGANIC MATTER DYNAMICS AND NUTRIENT CYCLING

In the humid tropical soils, earthworms play a determinant role on soil fertility by their action on soil organic matter turnover. Effects of endogeic earthworms on soil organic matter cycling are time-scale dependent. Their digestion leads to a sharp increase of mineralization during soil transit through the gut. In the earthworm's gut, microorganisms find optimal conditions for their activity due to the addition of water and mucus and degrade SOM into assimilable organic matter. Thus nutrients become available to plants (BAROIS & LAVELLE, 1986; MARTIN *et al.*, 1987). This small-scale effect leads to significant nutrient release at the scale of the days to weeks while the assimilation of soil organic matter by earthworm remains relatively low (MARTIN *et al.*, 1992). At a long time scale (months to years), a blocking of mineralization has been reported. MARTIN (1991) incubated casts and 2 mm-sieved control soil for 420 days. She showed that organic C was higher in control soil than in fresh casts but the mineralization was further maintained at a higher rate in control soil than in the casts and after [illegible]0 days of experiment, organic C was higher in casts than in control soil.

As a result, SOM dynamics is influenced by high mineralization at small-time scale during the gut transit, and low mineralization at long-time scale in casts. In ageing casts, decomposition is dramatically slowed probably due to physical protection of SOM in the compact structure of casts (BLANCHART *et* *al.*, 1993 ; MARTIN, 1991).

During the transit of soil through the earthworm gut, organic matter mineralization leads to nutrient release. LAVELLE *et al.* (1992b) studied nutrient release in casts of the peregrine earthworm *Pontoscolex corethrurus* (Glossosclecidae) fed with an Amazonian ultisol. The nutrient release was investigated in different aged casts (Figure 3). The results showed a sharp increase of N-biomass, NO^{3-} and NH^{4+} in fresh casts. After a few days N-biomass decreased and total mineral-N slowly increased with increase of NO^{3-} that was always higher in casts than in non-ingested soil.

These results showed that digestion of SOM by earthworms resulted in the release of a large amount of NH^{4+} with accumulation of N in the microbial biomass. Nitrification was more and more important as casts were ageing and ca. 20.4% of N lost from NH^{4+} and N biomass was converted to NO^{3-}. Lavelle *et al.* (1992b) estimated that a minimum amount of 50-100 kg of mineral N was released into the soil every year.

The total amount of assimilable phosphorus in fresh casts of the earthworm *Polypheretima elongata* fed with a vertisol in Martinique has been assessed by the method of the resin-P (Brossard, Laurent & Lavelle, in prep.). There was a significant ($P < 0.001$, t-test) 50% increase of P in casts as compared to non-ingested soil.

The production of large amount of N and assimilable P in soil might be useful if synchronized with plant demand and syn-localized with roots. The synchrony between plant demand and nutrient release is certainly the key-process of earthworm management in agricultural practices.

EARTHWORM ACTIVITY AND PLANT PRODUCTION

A 70 days pot experiment was conduced by Spain *et al.* (1992). Production of the Gramineae *Panicum maximum* was studied according to different earthworm (*Millsonia anomala*, Megascolecidae) biomass introduced in pots. Overall production was highly increased in presence of the earthworms. A positive relationship between introduced biomass of earthworms and plant production was found. Nevertheless a treshold appeared which showed the absence of effect or a negative effect of earthworms if introduced density is too high. In this case the soil becomes very compact or sticky. These kind of results confirm similar results gained from short time experiment (Pashanasi et al., 1992b).

At Yurimaguas (Peruvian Amazonia) maize grain production was studied in two systems : treatment in which earthworms were killed with carbofuran and treatment with introduction of 36 $g.m^{-2}$ of the earthworm species *Pontoscolex corethrurus* . The results of the first five crops are available (Pashanasi et al., 1992a) (Figure 4). No fertilizers were applied until the third crop at which grain production in the "no earthworms" treatment was very low. It is important to notice that for the first 3 crops, grain production remained always higher in presence than in absence of earthworms. After application of fertilizers, the fourth crop showed a weak but not significant increase of production in the "without earthwoms" treatment . The fifth crop reveals a highly significant increase of grain production in presence of earthworms. Even in a situation in which fertilizers are used, earthworms allow a significant increase of production. This may be due to a better synchrony between plant demand and nutrient release.

CONCLUSIONS AND PERSPECTIVES

In the humid tropics, many studies showed that earthworms play an important role in the conservation of soil structure through the formation of stable macroaggregates, in the maintenance of soil porosity and in the organic matter decomposition and nutrient release. Thus their management could be beneficial in agro-ecosystems and particularly in two different ways : i) the sustainability and improvement of soil fertility in low-input agriculture and ii) the restoration of degraded soils after long time of continuous cropping.

The first step of management is to conserve the existing soil fauna by a moderate use of pesticides, minimum tillage practices and maintenance of a vegetal cover. The second step is to introduce new populations of opportunistic earthworms which can adapt to a new locality. This step requires a good knowledge of these species and of their effects on the soil in which they will be introduced.

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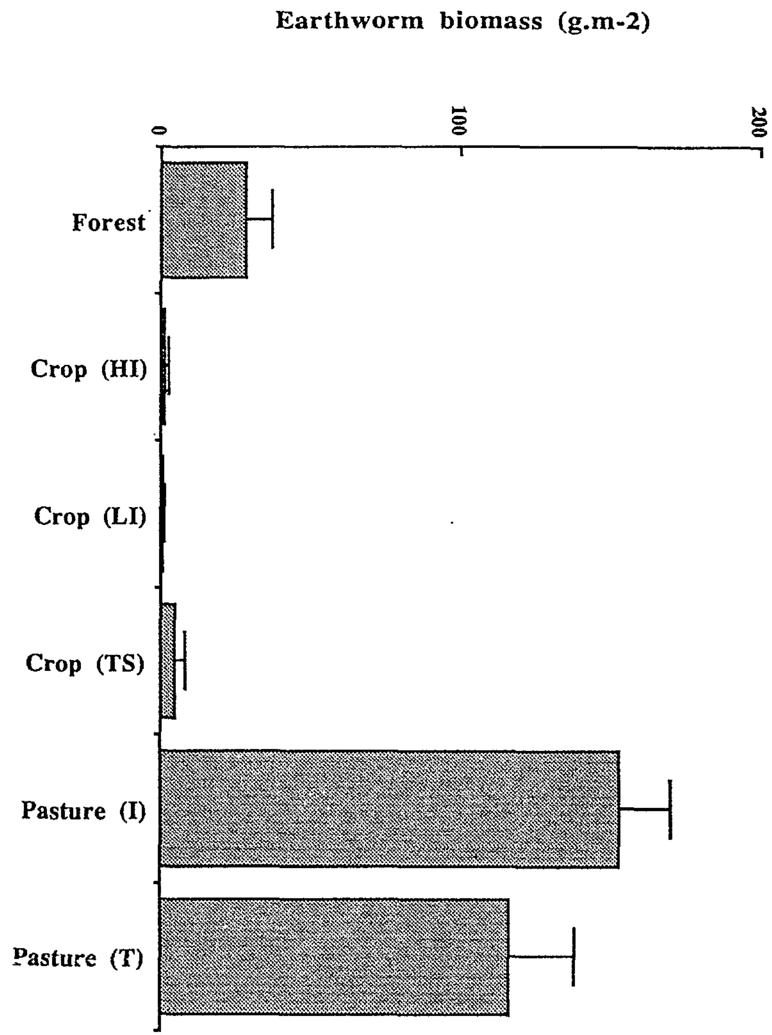
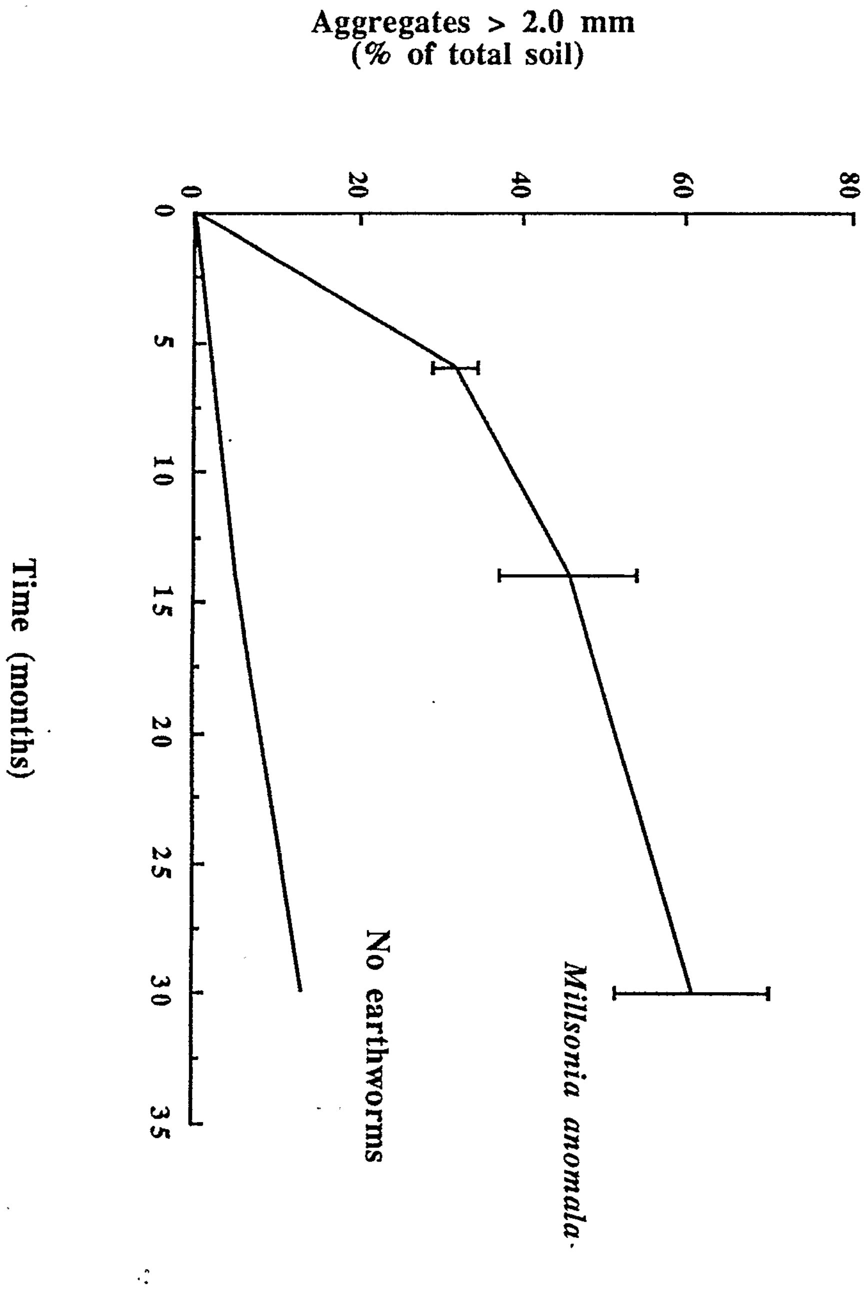
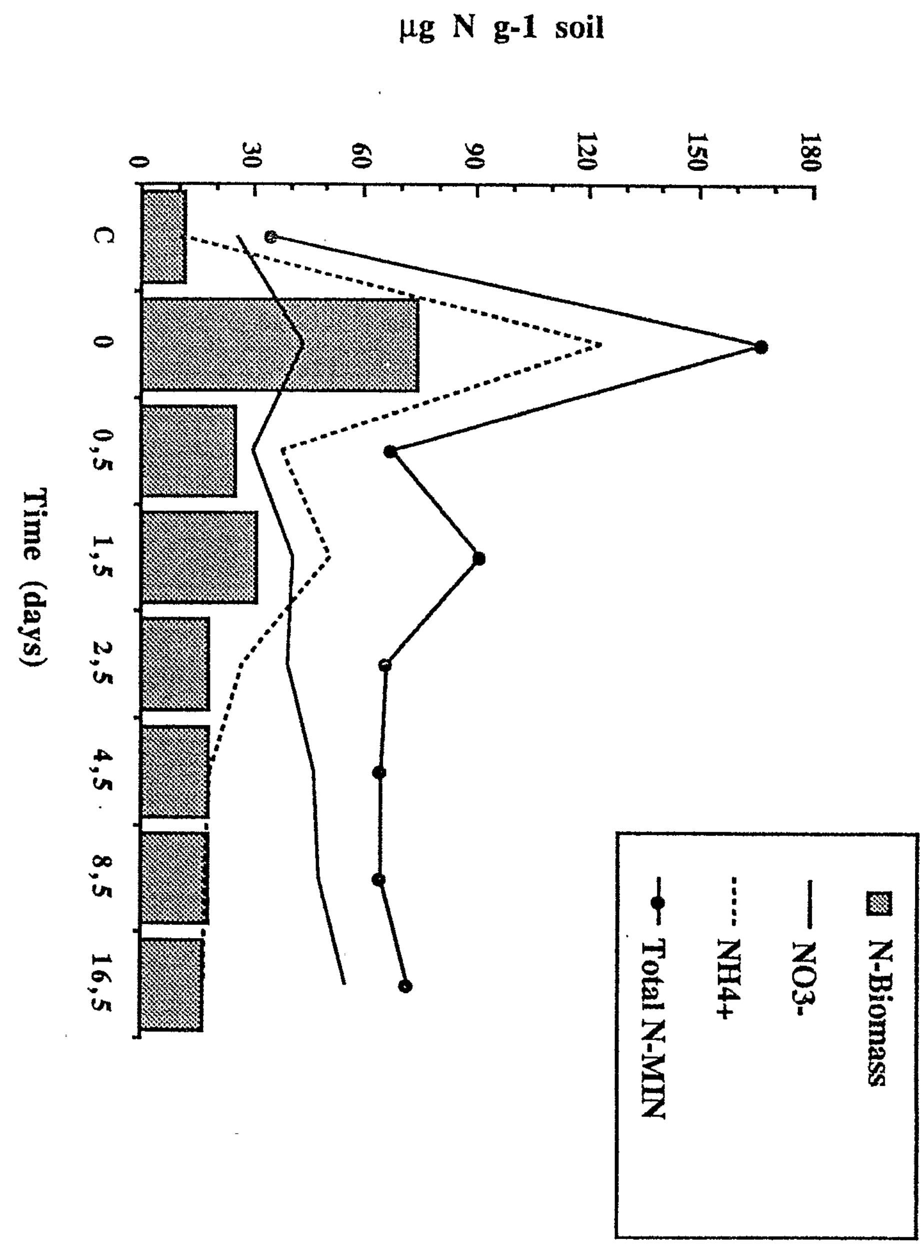
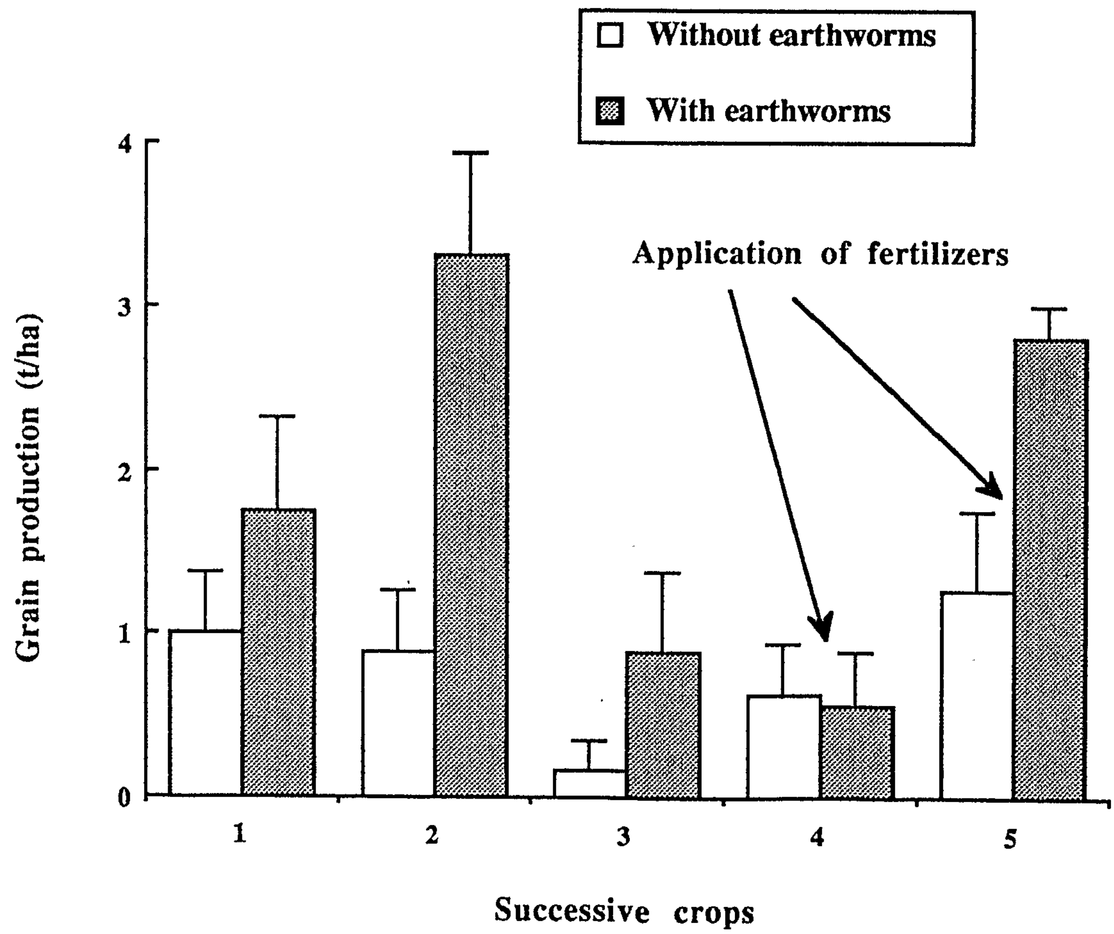




Aggregates > 2.0 mm
(% of total soil)
0
20
40
60
80
0
5
10
15
20
25
30
35
Time (months)
Millsonia anomala
No earthworms



µg N g-1 soil
0
30
60
90
120
150
180
C
0
0,5
1,5
2,5
4,5
8,5
16,5
Time (days)
N-Biomass
NO3-
NH4+
Total N-MIN


Without earthworms
With earthworms
Application of fertilizers
Grain production (t/ha)
0
1
2
3
4
1
2
3
4
5
Successive crops