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Effects of a tropical geophagous earthworm, *Millsonia anomala*, on some soil characteristics, on maize-residue decomposition and on maize production in Ivory Coast

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Abstract

Maize was grown under field conditions in the presence and absence of the tropical endogeic earthworm *Millsonia anomala* (Omodeo and Vaillaud, 1967) in soil of a secondary forest of central Ivory Coast. Experimental units were isolated by PVC sheets to limit earthworm movements. Decomposition and redistribution of nitrogen from maize crop residues incorporated in the soil were monitored using ^{15}N-labelled residues.

The density of *M. anomala* decreased from 50 to 15.9 m^{-2} during the cultivation period (90 days). Activity of *M. anomala* significantly modified the structure of the soil by increasing the proportion of large aggregates (over 2 mm in diameter). Maize production was increased by 12% for stalks and 18% for grains in the presence of earthworms. Nitrogen contained in the maize residue was more efficiently used by plants grown in the presence of earthworms; the real coefficient of utilisation of the organic residue increased from 9 to 11% in the presence of *M. anomala*. Nonetheless, total nitrogen exportation was not significantly different between the two treatments. Furthermore, N from the organic residues left after the cultivation period was less easily assimilated by plants in treatments with earthworms.

Keywords: Earthworms; Tropics; Maize; ^{15}N; Soil physical characteristics

1. Introduction

Tropical geophagous earthworms significantly affect the physical structure of soil (Aina, 1984; Lee and Ladd, 1984; Lal, 1988; Blanchart et al., 1990); they also have major effects on soil organic matter dynamics (Martin, 1991a; Lavelle and Martin, 1992). Earthworms through their feeding and mechanical activities have a strong impact on decomposition of plant residues. At the scale of fresh casts following deposition for a few weeks, they generally accelerate mineralisation. Furthermore, soil aggregation, the structure of porosity and connectance among pores are significantly changed (Blanchart, 1990). All these factors may affect plant production. Several studies, in culture pots, have demonstrated some improvement in cereal and grass yields due to the addition of temperate-climate earthworms (Van Rhee, 1965; Atlavinyte, 1974). However, very little is known of the effects of non-lumbricid earthworms on plant pro-

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duction. In a preliminary pot experiment conducted in Ivory Coast, inoculation of soil with earthworms resulted in a significant increase in maize and grass production (Spain et al., 1992). An experiment was set to test the hypothesis that enhanced decomposition of ^{15}N labelled maize residues mixed with the upper few centimetres of soil and changes in soil physical structure resulting from earthworm activi-

Soils are tropical ferruginous (ferralsols, FAO–UNESCO classification) derived from granitic parent material. In the experimental plot, soil was sampled for chemical analyses in December 1991, prior to maize cultivation. Soil texture is sandy and the clay content is low (Table 1). Organic and nutrient contents are low and they decrease very rapidly from the upper soil layer to 40 cm depth.

50 cm, leaving a rim of 10 cm above the surface level. Each microplot was divided (with a PVC sheet) into two parts that comprised one-third and two-thirds of the total surface area, respectively.

density and biomass of earthworms, recovery of ^{15}N in the different compartments (soil, plant) and soil physical and chemical analyses.

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Table 3
Mean density (m^{-2}) and biomass (g fresh weight m^{-2}) of *M. anomala* and other earthworms in experimental units (with (MA +) and without (MA −) *M. anomala*) at the different sampling dates

				Day 0	Day 35	Day 70	Day 90
MA +	*M. anomala*	Density	Juveniles	30	24	5	8.5
			Adults	20	21	2	7.4
			Total	50	45	7	15.9
		Biomass	Juveniles	11.8	15.2	0.2	0.55
			Adults	28.2	26.9	2.1	7.90
			Total	40.0	42.1	2.3	8.45
		Mean weight	Juveniles	0.39	0.63	0.04	0.07
			Adults	1.34	1.28	1.06	1.06
	Others	Density		0.0	2.4	13.4	15.6
		Biomass		0.0	1.60	3.07	3.98
MA −	*M. anomala*	Density		0.0	2.0	2.0	0.4
		Biomass		0.0	2.45	3.25	0.40
	Others	Density		0.0	0.0	34.6	11.4
		Biomass		0.0	0.0	4.61	2.95

microbial catabolism. Nitrogen from the hydrolysable distillable fraction originates from hexosamines and amides of certain amino acids. The Nnh fraction that is less well characterised would mainly comprise heterocyclic nitrogen (Stewart et al., 1963; Jocteur Monrozier and Andreux, 1981).

Nitrogen derived from labelled litter (Ndfll) and the real utilisation coefficient (RUC) of this residue were calculated to determine whether earthworm activities improve the utilisation by the plant of N from decomposing litter. Values are calculated using the following equations (Ganry, 1990):

1. percentage of the total plant nitrogen derived from labelled litter

$$\mathrm{Ndfll}(\%) = \frac{E_{\mathrm{pl}}}{E} \times 100$$

excesses were measured in four plant components (stalks, leaves, ears and roots).

2.2.5. Aggregation (90 days after sowing)

The size distribution of soil aggregates at harvest was assessed by dry sieving monoliths (20 cm × 20 cm × 20 cm) in five replicates per treatment. After monoliths had been separated into two layers (0–10 and 10–20 cm) they were separately broken into large blocks (about 800 cm^3) and air-dried to a moisture content of about 5–6% dry weight (pF ≈ 4). Aggregates were separated by dropping the air dried blocks from a constant height of 1.5 m onto a hard surface (Blanchart, 1992). Fragments were further air dried and sieved on meshes of the following sizes: 10 mm, 6.3 mm, 5 mm, 2 mm, 1 mm, 630 μm, 500

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water level to the cylinder top was recorded during 1 h (adapted from Anderson and Ingram, 1992).

2.2.7. Maize residue decomposition

Decomposition of the maize residue was measured during a period of 8 weeks. The soil was removed from cylinders (20 cm diameter, 20 cm depth). Wire netting (0.1 mm mesh) was driven vertically to the bottom of the hole and a mosquito net placed at the bottom to avoid invasion by native worms. Maize residues (110 g m^{-2}; fragments 1–2 cm long) were mixed into the upper 10 cm soil layer in the small enclosures. In half of the enclosures, two young *M. anomala* were introduced. Three replicates per treatment were sampled every week. Soil organic matter over 2 mm in size was separated by flotation and maize residues were sorted under a stereo microscope, oven-dried (105°C) and weighed. Maize residues less than 2 mm in size were not recovered.

3. Results

3.1. Earthworms

The density of *Millsonia anomala* populations at harvest decreased significantly from 50 to 15.9 m^{-2} over the course of the experiment (Table 3). Density of *M. anomala* in the non-inoculated treatment remained less than 2 m^{-2}. Since the number of earthworms of other species found in the units increased

Table 4

Effect of earthworm inoculation on the distribution of aggregates (mean values) of different size classes (with (MA +) and without (MA −) *M. anomala*) in the 0–10 and 10–20 cm strata at the end of the experiment

Aggregate size class	Depth (cm)	MA − ($n = 9$)	MA + ($n = 9$)	*P* (Student's test)
0–250 μm	0–10	21.7	16.7	< 0.05
	10–20	17.0	16.6	NS
250–315 μm	0–10	4.3	3.3	< 0.05
	10–20	3.8	3.6	NS
315–400 μm	0–10	13.2	9.4	< 0.01
	10–20	12.0	10.9	NS
400–500 μm	0–10	9.0	7.0	< 0.05
	10–20	8.5	8.3	NS
500–630 μm	0–10	7.6	5.4	< 0.05
	10–20	7.6	6.8	NS
630 μm–1.0 mm	0–10	12.4	9.7	< 0.01
	10–20	12.8	11.3	NS
1.0–2.0 mm	0–10	7.0	6.3	NS
	10–20	7.6	6.3	NS
2.0–5.0 mm	0–10	5.6	6.6	NS
	10–20	5.7	4.8	NS
5.0–6.3 mm	0–10	1.6	2.6	NS
	10–20	1.7	1.8	NS
6.3–10 mm	0–10	6.2	13.2	< 0.01
	10–20	6.8	8.6	NS
> 10 mm	0–10	11.2	19.9	< 0.01
	10–20	16.5	20.9	NS
Σ(0–0.4 mm)	0–10	39.3	29.4	< 0.05
	10–20	32.8	31.2	NS
Σ(0.4–2 mm)	0–10	36.1	28.3	< 0.01
	10–20	36.5	32.7	NS
> 2 mm	0–10	24.6	42.2	< 0.01
	10–20	30.7	36.1	NS

NS, not significant.

Table 5

Maize production: vegetative parts and grains, number of grains, weight of 250 grains and proportion of fertile plants at the different sampling dates (with (MA +) and without (MA −) *M. anomala*) (probability values are given for unilateral *t*-test on paired values)

	Day 35			Day 70			Day 90		
	MA −	MA +		MA −	MA +		MA −	MA +	
Stalk production (g per plant)	5.0	5.1	NS	44.0	41.4	NS	57.0	64.0	< 0.05
Grain production (g per plant)							18.1	21.4	< 0.10
Weight of 250 grains (g)							31.1	33.8	< 0.05
No. of grains (per ear)							184	198	NS
Proportion of fertile plants (%)							64	65	NS

NS, non-significant difference between MA + and MA − .

with time from 0 to 15.6 m^{-2}, it is believed that they progressively colonised the units from the outside (Table 3).

Changes in the demographic structure of the population of *M. anomala* give some clues to the interpretation of changes observed in the earthworm populations. During the first 35 days no great changes occurred (Table 3). However, after 65 days, the density of juveniles and adults was substantially reduced. Most juveniles found at this time were only 1–4 weeks old, suggesting that the reproduction period had occurred some 40 days after introduction of the earthworms and, later on, density had decreased sharply since a large number of worms had died or possibly escaped.

3.2. Soil structure

At harvest, aggregate size distribution was significantly different in the two treatments only in the 0–10 cm depth strata (Table 4), indicating that earthworms had concentrated their activity in the upper soil layer. The proportion of aggregates larger than 2 mm was increased from 24.6% in the non-inoculated treatments to 42.2% in the inoculated treatment. Furthermore, earthworm activities significantly increased the proportion of larger aggregates (over 6.3 mm diameter). These classes of aggregates were mainly composed of casts of *M. anomala* in treatments with earthworms. On the other hand, all classes of aggregates smaller than 1 mm were represented significantly less in the presence of earthworms.

3.3. Water infiltration

Water infiltration in soil was significantly reduced (by 25%) in the presence of *M. anomala*. In 1 h, the quantity of water infiltrated was 200 mm and 250 mm in the MA + and MA − enclosures, respectively.

Table 6

Elements of the N budget of maize plants: N contents in plant, N derived from labelled litter (Ndfll) and percentage of nitrogen of the labelled litter taken up by the plant in the different parts of the plant (RUC) (with (MA +) and without (MA −) *M. anomala*)

	N content (%)		Ndfll (%)		RUC (%)	
	MA −	MA +	MA −	MA +	MA −	MA +
Stems	0.43	0.48	5.50	6.44	1.45	1.73
Leaves	1.56	1.70	4.90	5.68	6.40	7.85 *
Ears	1.22	1.14	4.83	5.89	0.71	0.99
Aerial parts	1.07	1.19	4.99	5.86	8.56	10.58 *
Roots	0.61	0.60	7.36	6.24	0.46	0.37 *
Whole plant	1.05	1.15	5.09	5.88	9.03	10.95 *

Student's *t*-test: * $P < 0.10$.

3.4. Maize production

%

[illegible]

Table 8
Percentage of ^{15}N recovered in the soil in each N fraction at two depths (Student's *t*-test, * $P < 0.05$) (with (MA+) and without (MA−) *M. anomala*)

	0–10 cm			10–20 cm		
	MA−	MA+		MA−	MA+	
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]

The proportion of this fraction was higher in the N derived from the maize residue than from the whole soil.

Furthermore, there was an effect of the activity of earthworms on the distribution of the N from the maize residue in the chemical N fractions: in the

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anomala are geophagous endogeic earthworms that feed on humified organic matter. Hence, they do not construct subvertical burrows that link the upper layers to deeper strata; in contrast, the majority of their movement is subhorizontal and they refill with fresh casts most of their galleries.

The aggregation of soil due to earthworm activity may have two undesirable consequences on the soil system—soil compaction and mortality of *M. anomala*. These earthworms are not able to reingest their own casts and when they have ingested a significant proportion of soil, they may starve and die. A possible way to balance these effects would be to introduce, simultaneously to this species, small filiform earthworms of the family Eudrilidae (Blanchart, 1990) that have the ability to break down casts of larger worms into smaller aggregates.

The decrease of *M. anomala* biomass in the experimental units may have been due to excessive soil macroaggregation and rapid decomposition of the organic residues that had been introduced at the beginning of the experiment. In the absence of added organic residues, these worms ingest soil organic matter but growth is slower (Zaidi, 1985; Martin and Lavelle, 1992). Results of the decomposition experiment showed that 90% of organic residues larger than 2 mm had disappeared after 45 days. Earthworms most probably suffered from the shortage of

more, N lost from earthworm biomass may not have benefitted the plant since the worms may have partly escaped the experimental units when conditions became difficult (Martin, 1991b).

Worms improve the use of nitrogen from labelled residues but total nitrogen exportation was not higher. The actual efficiency of organic residue utilisation was 11% in inoculated treatments. This efficiency was much lower than values measured with mineral fertiliser (Ganry, 1990; Balabane and Balesdent, 1992). The amount of nitrogen incorporated in plants is correlated with the quantity of residue decomposed (Müller and Sundman, 1988). Earthworm activity accelerated the release of nutrients from residues to the benefit of plants (Mackay and Kladivko, 1985; Cheshire and Griffiths, 1989). Furthermore, in the presence of worms, N incorporated in soil organic matter was more stable and the proportion of non-hydrolysable nitrogen increased. Worm activity enhanced the storage of residue-N in humified forms in the soil at the expense of fractions which could be easily mobilised. These results might indicate a better synchrony between plant demand and nitrogen availability in soil in the presence of earthworms during the maize growth cycle. Nitrogen derived from labelled litter left in the soil after the crop had been harvested, was potentially less available to plants in inoculated treatments than in consoil fertility in low input agricultural systems of the humid tropics by manipulating earthworm communities'.

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