Production and nutrient content of earthworm casts in a tropical agrisilvicultural system

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Abstract

Earthworm surface cast production and nutrient turnover through casts were measured for 3 years in a 17-year-old timber plantation in southern Cameroon after selective reduction to two timber stand densities (TSDs) and understorey cropping with plantain and tannia. Neither understorey cropping nor timber stand density treatments had significant effects upon cast production in any year. Mean cast production in cropped plots was 35.7 Mg ha⁻¹ in the first year, 34.9 Mg ha⁻¹ in year 2 and 30.1 Mg ha⁻¹ in year 3. This was 63%, 84%, and 65%, respectively, of cast production in undisturbed, unthinned timber plantation plots. In comparing cast nutrient concentrations between years 1, 2 and 3, there were highly significant correlations for nearly all nutrients in control plots but fewer such correlations in the low TSD. In cropped plots, none of earthworm parameters was correlated with nutrient concentrations of slash or amounts of slash applied to the soil surface at establishment. There were positive correlations between cast N and litterfall N (kg ha⁻¹ y⁻¹) in both year 2 (cast N = 0.49 x litterfall N + 61.7, r² = 0.46) and year 3 (cast N = 0.38 x litterfall N + 55.6, r² = 0.42). The ratio of soil:cast nutrient concentrations were related by negative power functions to soil nutrient concentrations for all nutrients and organic carbon. This suggests that earthworm communities adjust to lower soil nutrient concentrations by increasing their selectivity and thus produce relatively higher quality casts on poorer soil.

Keywords: Agroforestry; Southern Cameroon; Terminalia ivorensis; Timber stand density

1. Introduction

A central tenet in agroforestry research in the humid tropics is that trees improve or maintain soil fertility and ecosystem function (Sanchez et al., 1985; Ingram, 1990). Brown et al. (1994) hypothesised that soil fertility in tropical, derived systems is maintained ‘by mimicking a forest ecosystem with perennials or perennial and annual mixtures’. However the mechanisms by which this is realised; maintaining soil organic matter levels, deep nutrient capture from subsoil layers, tighter nutrient cycling, reduction of topsoil acidity through base cation cycling, and shade from the tree canopy improving soil biological activity and nitrogen mineralisation, have not all been proven or only so under limited circumstances (Sanchez, 1995). The importance of earthworms in these mechanisms is considered to be high (Swift et al., 1994; Lavelle et al., 1998), as ecosystem engineers’ (sensu Lavelle, 1994) in litter transformation, and nutrient and organic carbon deposition (Hauser et al., 1997; Norgrove et al., 1998).

When trees are removed from land-use systems, such as when land is cleared, slashed, burned and tilled in slash and burn agriculture, earthworm density, diversity and activity are reduced. This has been shown in south-west Nigeria (Critchley et al., 1979; Cook et al., 1980; Hauser and Asawalam, 1998) where the earthworm fauna is dominated by Hyperodrilus africanus.
(Beddard) and the epigeic *Eudrilus eugeniae* (Kinberg) (Madge, 1969); in the Peruvian Amazon (Lavelle and Pashanasi, 1989); in southern Cameroon (Norgrove et al., 1998) and in south east Mexico (Fragoso et al., 1993, 1995). When natural forests have been replaced by forest plantations, earthworm populations have been maintained or even increased (Blanchart and Julka, 1997) in some cases, yet reduced to lower levels in others (Zou and González, 1997; González et al., 1996). Zou and Bashkin (1998) showed that when previously cropped land was reforested, earthworm populations recovered; however, epigeic and anecic species, present in natural successional systems, remained absent.

While forest cover may be the most sustainable land-use in the humid tropics, it is unfeasible in areas with high human population densities; smallholder farmers need the land to meet their immediate need, food production. One compromise, postulated to maintain ecosystem function, and provide food and timber is combining silviculture with agriculture: growing food crops between tree seedlings at plantation establishment and then introducing a cropping phase at each routine thinning of the timber plantation, usually every 6 years. Cropping during timber plantation establishment, known as ‘taungya’, is viable and well documented, yet there have been no studies on crop production later in the silvicultural cycle. Lower timber stand densities than those normally used in timber plantations may be needed to allow sufficient light and reduced competition for the understorey crop to produce acceptable yields. Any reduction in timber stand density may affect ecosystem functioning, earthworm activity and nutrient cycling. There has been little research on the influence of thinning upon nutrient cycling in plantations (Carltye, 1995) and any change may depend on the crop management system used for the understorey crops.

Here we establish the effects of two timber stand densities (192 and 64 trees ha\(^{-1}\)), imposed by selective felling and various low-input crop management systems, upon surface cast production and nutrient deposition by earthworms in a 17-year-old timber plantation with understorey crops in the humid forest zone of Cameroon for three years. Cast production was also monitored in undisturbed timber plantation control plots.

### 2. Materials and methods

#### 2.1. Site

The experiment was established in April 1995 in a 17-year-old *Terminalia ivorensis* A. Chev. plantation in the Mbalmayo Forest Reserve in southern Cameroon (3° 51N and 11° 27E). Initial land clearance in 1978 was manual (Lawson, 1995). The land is covered with semi-deciduous adult and young secondary forest. Altitude is 540 m above sea level. Average annual rainfall is 1513 mm in a bimodal distribution. Rains usually start in March and end in early July, followed by a short dry season of 6 to 8 weeks, then recommence in September and stop at the end of November. In the years described here, annual rainfall was 1327, 1586 and 1685 mm, respectively. Average annual insolation is 1645 h. The soil is classified as a clayey, kaolinitic, isohyperthermic, Typic Kandiudult (Hulugalle and Ndi, 1993) and is acid in the subsoil. The earthworm fauna of the Reserve has not been fully described. However, in a preliminary assessment, four earthworm species were found: *Rosadrilus camerunensis* Cognetti; *Eminoscolex lamani* Michaelsen; *Dichogaster mundamensis* (syn *Diplothecodrilus mundamensis*) Michaelsen; *Nematogenia panamaensis* Eisen (Csuzdi pers. comm.). The majority of casts produced were globular; few were turret-shaped. Maximum diameter was approximately 10 cm. Sub-surface casts have not been found in Mbalmayo after sampling down to 2 m in pits in 80 locations in this experiment and cropped fields with various degrees of soil compaction. It is thus assumed that here most of casts are egested on the soil surface (Norgrove and Hauser, 1998).

#### 2.2. Design and establishment

The experiment had a factorial split-plot design with timber stand density (TSD) treatments as main-plots: *T. ivorensis* at 192 trees ha\(^{-1}\) (high TSD), and; *T. ivorensis* at 64 trees ha\(^{-1}\) (low TSD). The experiment was replicated in four blocks. Main-plots were 50 m × 50 m. Each main-plot was divided into four sub-plots, 25 m × 25 m, containing four crop management treatments: sole plantain (*Musa* spp. AAB sub-group plantain ‘French’ cv. ‘Essong’; *Musaceae*) mulched with the slashed material; sole tannia (*Xanthosoma sagittifolium* (L.) Schott, *Araceae*), intercrop of plantain-tannia mulched with the slashed material; and sole plantain, where the slashed material was burned before planting.

In addition, there was an undisturbed, non-cropped *T. ivorensis* stand (control), not divided into sub-plots, in each of the four blocks.

Manual slashing of the understorey was started on 11 April, 1995 and the tree stand was mapped. TSDs were imposed on 27 April 1995 by felling the shorter or crippled trees first, leaving the marketable timber trees. In the plots to be burned, slash was removed from the zones within 50 cm of standing tree trunks to prevent scorching. Plots were burned on 1 May 1995. Plantain planting density was 1600 plants ha\(^{-1}\) on a 2.5 m × 2.5 m square configuration thus 100 plants per sub-plot. Tannia planting density was 20,408 plants...
ha⁻¹ on a 0.7 m × 0.7 m square configuration. Planting was from 2–6 May 1995. Plots were weeded by manual slashing with machetes approximately every four months.

2.3. Measurement of surface casting

Surface casting was measured in 0.5 m × 0.5 m frames (after Evans and Guild, 1947), with four frames per plot. Given the inherent heterogeneity within a tree stand in terms of distance from the trees, the two most frequent strata at the given densities were calculated as 7 m from one tree for the low density and within 8 m of four trees in the high density. Frames were randomly allocated within these strata. Areas within 2.5 m of plot borders were not used.

Any cast material found in frames before sampling started was discarded. All surface casts were collected from the frames twice per week from 1 June, 1995 until cast production ceased. Frames were checked for cast production after the first rains in March 1996 and March 1997 and cast collection continued until casting ceased. Casts were dried at 65°C for 48 h after each sampling and the dry weight per frame was recorded. From cropped plots, cast material was pooled by plot and by year. For the control plots, material was pooled by year for each frame separately. Casts were analysed for pH, organic C, total N and exchangeable (exch.) cations after the end of each casting season. Casts in the second year only were analysed for texture.

2.4. Soil and mulch sampling

Soil was sampled in May 1995 at planting and after burning. Nine samples per sub-plot were taken on a rigid system at 3.5 m, 10.5 m, 17.5 m, 24.5 m and 31.5 m along the 35 m sub-plot diagonals. Mulch samples were taken simultaneously from a 1.41 m × 1.41 m area at each sampling point. Soil was then sampled at five points, at the corners and centre of the sampling area, and then bulked by depth: 0–10, 10–20, 20–30, 30–50, 50–70, and 70–100 cm. Samples at 0–10 cm and 10–20 cm depth were taken with soil cores (50 mm long and 50 mm diameter); deeper layers were sampled using an auger with an internal diameter of 25 mm. Soil and mulch samples were dried at 65°C to constant weight. Soil samples were passed through a 2.0 mm sieve. A sub-sample of each was ground to 0.5 mm and analysed for pH, organic C, total N and exch. cations. Due to cost constraints, only soil samples from plantain mulched, plantain burned and control plots were analysed. Mulch samples were bulked by sub-plot, ground to pass through a 0.5 mm sieve and retained for chemical analysis.

2.5. Litterfall sampling

Litterfall was collected for 2 years from September 1995 (Norgrove and Hauser, submitted). Litterfall was sampled in traps consisting of a circular metal frame of 0.28 m², mounted 1 m above the ground on a single wooden prop. Eight litter-traps were set per main-plot. The traps were arranged at 14, 28, 42 and 56 m along the main-plot’s 70 m diagonals. Litterfall was collected every week for 2 years and airdried. Samples were bulked over 4 weeks, separated into T. ivorensis leaves, fruits, and non-T. ivorensis leaves and other material, predominantly twigs. Branch fall (>5 cm diameter) was not sampled. Bulked samples were oven-dried at 65°C for 4 days then weighed to 1 × 10⁻⁴ g resolution. Data on litter is used here for correlations only.

2.6. Soil and cast analysis

pH was determined in a water suspension at a 2:5 soil:water ratio. Exchangeable (exch.) Ca²⁺, Mg²⁺, K⁺ and total P were extracted by the Mehlich-3 procedure (Mehlich, 1984). Cations were determined by atomic absorption spectrophotometry and P by the malachite green colorimetric procedure (Motomizu et al., 1983). Organic C was determined by Heanes' improved chromic acid digestion and spectrophotometric procedure (Heanes, 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner and Tabatabai, 1972). Soil and cast texture was determined using Day's procedure (Day, 1965)

2.7. Litter and mulch analyses

Samples were ground to 0.5 mm. Samples were digested according to Novozamsky et al. (1983). Total N was determined with an ammonium sensitive electrode (Powers et al., 1981). Total Ca, Mg, and K were analysed by atomic absorption spectrophotometry.

2.8. Statistical analysis

Data were analysed in SAS v 6.12 using the GLM procedure following the mixed model output with the randoms statement appropriate for split-plot designs and the repeated function for data from different years (SAS, 1989). As cast production ceases during the long dry season (December to March), then year 1 (y1) is defined as 1 June 1995 (4 weeks after planting) until December 1995, year 2 (y2) as March to December 1996 and year 3 (y3) as March 1997 to January 1998. The test criterion used for year-to-year comparisons was Wilks’ Lambda. The proportions of sand, clay and silt in casts were arc-sine transformed before analysis, as is appropriate for proportions (Sokal and
Rohlf, 1995). Exploratory analysis revealed that sample variances of cast amounts and nutrient concentrations were not correlated with the means so analyses were performed on untransformed data. Differences with probabilities of $P < 0.05$ are mentioned with the probability class ($P < 0.05$, $P < 0.01$, $P < 0.001$) in brackets.

3. Results

3.1. Quantities of casts

Cast collection started on 1 June in y1, after the start of the casting season. Casting ceased on 18 December, 1995, 29 weeks later. In y2, cast production started on 21 March and ceased on 6 December, 38 weeks later. In y3, cast production started on 19 March and ceased on 8 January the following calendar year, 42 weeks later.

Cast production was greater in the control than in the cropped plots in y1 and y3 ($P < 0.05$), however, there was no significant difference in y2 (Table 1). There was no significant difference in cast production between TSD treatments in any year and in the cumulative cast production over all years. There were no significant differences in cast production between crop management treatments in any year. Cast production in cropped plots averaged 35.7, 34.9 and 30.1 Mg ha$^{-1}$ across treatments in y1, y2 and y3, respectively. Cast production was lower (Wilks’ Lambda $< 0.05$) in the control in y2 than in y1 however remained stable in cropped plots. Cast production increased (Wilks’ Lambda $< 0.05$) in the control from y2 to y3, however, decreased in cropped plots (Wilks’ Lambda $< 0.05$).

3.2. Cast texture

There were no significant differences between TSD or between crop management treatments in the percentages of sand, clay and silt in casts. Across all treatments, averages were 62% sand, 24% clay, and 14% silt.

3.3. Nutrient concentrations in casts

There were no differences in cast pH between TSD or between crop management treatments within any year (Table 2). There were no significant differences in total N, organic C, exch. Ca$^{2+}$ and Mg$^{2+}$ concentrations between TSD or between crop management treatments within any year. Exchangeable K$^+$ concentration in casts from the forest control was lower than from cropped plots in y1 ($P < 0.05$), y2 ($P < 0.05$) and y3 ($P < 0.01$). In y3, casts from low TSD treatments had higher K$^+$ concentrations ($P < 0.001$) than those from high TSD treatments. There were no differences in cast nutrient concentrations between crop management treatments.

From y1 to y2 there were decreases (all Wilks’ Lambda $< 0.001$) in total N, organic C, exch. Ca$^{2+}$ and Mg$^{2+}$ cast concentrations in all treatments. There were no significant changes in K$^+$ concentrations between y1 and y2. From y2 to y3, there were no significant differences in total N, exch. Ca$^{2+}$ and Mg$^{2+}$ cast concentrations. Organic carbon concentration in casts increased (Wilks’ Lambda $< 0.001$) yet K$^+$ concentration decreased (Wilks’ Lambda $< 0.001$) from y2 to y3.

Correlations over time for cast amounts and nutrient concentrations in casts, separated by main-plot treatments, are in Table 3. Correlations between them are in Table 4.

3.4. Amounts of nutrients deposited in casts

In y1, more total N ($P < 0.01$), C$_{org}$ ($P < 0.05$) and Mg$^{2+}$ ($P < 0.05$) were deposited in casts in the forest control than in the cropped plots (Table 5). In y2, none of these differences was significant. In y3, more C$_{org}$ ($P < 0.05$) and Mg$^{2+}$ ($P < 0.05$) were deposited in casts in the forest control than in the cropped plots. There were no other differences. Neither TSD nor cropped treatments had any significant effects on amounts of any nutrient deposited in surface casts within any year.

Less C$_{org}$ (Wilks’ Lambda $< 0.01$), Ca$^{2+}$ (Wilks’ Lambda $< 0.01$) and Mg$^{2+}$ (Wilks’ Lambda $< 0.01$) were deposited in casts in y2 than in y1 in all treat-
ments. There was no significant difference in the amount of K⁺ deposited in casts between y1 and y2. From y2 to y3, there were decreases (Wilks’ Lambda < 0.001) in the amount of K⁺ deposited in all treatments. There were no significant differences in the amounts of total N, exch. Ca²⁺ or Mg²⁺ deposited between y2 and y3.

3.5. Comparison of cast and topsoil chemical properties

The average nutrient concentrations of topsoil (0–10 cm depth) across the site were 1.67 mg g⁻¹ total N, 17.7 mg g⁻¹ Corg, 0.42 mg g⁻¹ exch. Ca²⁺, 0.133 mg g⁻¹ Mg²⁺ and 0.082 mg g⁻¹ K⁺. Average cast concentrations were 1.84 for total N, 1.93 for Corg, 3.07 for exch. Ca²⁺, 2.39 for exch. Mg²⁺ and 1.65 for exch. K⁺ times higher than average topsoil (0–10 cm) concentrations. There were negative, power function relationships between the cast:soil ratio and soil concentrations at 0–10 and at 10–20 cm depth (Fig. 1a–e).

3.6. Relationships between casts and slash and litterfall

There were no significant correlations (P > 0.1) between cast production, nutrient concentration or nutrient amounts in casts in the first year and amounts of slash, nutrient concentrations or nutrient amounts in the slash. There were no significant correlations (P > 0.1) between cast production and litterfall amounts in y2 and y3. N concentrations in litterfall and amounts of N deposited in casts were correlated in both y1 and y2 (Fig. 2b).

<table>
<thead>
<tr>
<th></th>
<th>µN</th>
<th>Corg</th>
<th>Ca²⁺</th>
<th>Mg²⁺</th>
<th>K⁺</th>
<th>pH (H₂O)</th>
</tr>
</thead>
<tbody>
<tr>
<td>y1 High TSD</td>
<td>3.13 (0.18)</td>
<td>34.7 (1.50)</td>
<td>1.19 (0.09)</td>
<td>0.292 (0.018)</td>
<td>0.125 (0.006)</td>
<td>5.71 (0.07)</td>
</tr>
<tr>
<td>Low TSD</td>
<td>3.01 (0.16)</td>
<td>34.5 (1.62)</td>
<td>1.02 (0.07)</td>
<td>0.282 (0.014)</td>
<td>0.142 (0.009)</td>
<td>5.65 (0.10)</td>
</tr>
<tr>
<td>P (TSD)</td>
<td>0.72m</td>
<td>0.93m</td>
<td>0.43m</td>
<td>0.75m</td>
<td>0.32m</td>
<td>0.49m</td>
</tr>
<tr>
<td>Control</td>
<td>3.36 (0.40)</td>
<td>34.1 (4.73)</td>
<td>1.11 (0.29)</td>
<td>0.280 (0.049)</td>
<td>0.086 (0.014)</td>
<td>5.71 (0.11)</td>
</tr>
<tr>
<td>P (con v TSD)</td>
<td>0.47m</td>
<td>0.90m</td>
<td>0.98m</td>
<td>0.85m</td>
<td>0.020</td>
<td>0.83m</td>
</tr>
<tr>
<td>y2 High TSD</td>
<td>2.36 (0.08)</td>
<td>28.9 (0.77)</td>
<td>0.79 (0.06)</td>
<td>0.225 (0.014)</td>
<td>0.122 (0.006)</td>
<td>5.74 (0.05)</td>
</tr>
<tr>
<td>Low TSD</td>
<td>2.41 (0.07)</td>
<td>26.8 (0.77)</td>
<td>0.72 (0.04)</td>
<td>0.196 (0.009)</td>
<td>0.125 (0.006)</td>
<td>5.93 (0.10)</td>
</tr>
<tr>
<td>P (TSD)</td>
<td>0.52m</td>
<td>0.11m</td>
<td>0.55m</td>
<td>0.15m</td>
<td>0.69m</td>
<td>0.18m</td>
</tr>
<tr>
<td>Control</td>
<td>2.52 (0.27)</td>
<td>28.8 (2.71)</td>
<td>0.70 (0.20)</td>
<td>0.211 (0.035)</td>
<td>0.089 (0.009)</td>
<td>5.79 (0.10)</td>
</tr>
<tr>
<td>P (con v TSD)</td>
<td>0.45m</td>
<td>0.62m</td>
<td>0.67m</td>
<td>0.99m</td>
<td>0.021</td>
<td>0.16m</td>
</tr>
<tr>
<td>y3 High TSD</td>
<td>2.51 (0.06)</td>
<td>32.0 (0.67)</td>
<td>0.78 (0.06)</td>
<td>0.195 (0.011)</td>
<td>0.084 (0.004)</td>
<td>5.58 (0.08)</td>
</tr>
<tr>
<td>Low TSD</td>
<td>2.55 (0.05)</td>
<td>31.1 (0.51)</td>
<td>0.67 (0.04)</td>
<td>0.207 (0.006)</td>
<td>0.114 (0.006)</td>
<td>5.78 (0.06)</td>
</tr>
<tr>
<td>P (TSD)</td>
<td>0.64m</td>
<td>0.39m</td>
<td>0.92m</td>
<td>0.41m</td>
<td>0.0001***</td>
<td>0.95m</td>
</tr>
<tr>
<td>Control</td>
<td>2.34 (0.21)</td>
<td>31.5 (2.33)</td>
<td>0.67 (0.16)</td>
<td>0.209 (0.035)</td>
<td>0.069 (0.007)</td>
<td>5.60 (0.07)</td>
</tr>
<tr>
<td>P (con v TSD)</td>
<td>0.16m</td>
<td>0.98m</td>
<td>0.27m</td>
<td>0.75m</td>
<td>0.0031***</td>
<td>0.59m</td>
</tr>
</tbody>
</table>

*a* Mean with standard error in brackets. n = 16 for TSD treatments, n = 4 for control. *P < 0.05, **P < 0.01, ***P < 0.001.

### Table 3

Pearson correlation coefficients for cast parameters within TSD and control treatments between years (n = 16)*

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Low</th>
<th>High</th>
<th>Con</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y1/y2</td>
<td>y2/y3</td>
<td>y1/y3</td>
</tr>
<tr>
<td>Mg ha⁻¹</td>
<td>0.65**</td>
<td>0.67**</td>
<td>0.80***</td>
</tr>
<tr>
<td>µN</td>
<td>ns</td>
<td>0.51*</td>
<td>ns</td>
</tr>
<tr>
<td>mg g⁻¹</td>
<td>ns</td>
<td>0.88***</td>
<td>ns</td>
</tr>
<tr>
<td>Corg</td>
<td>0.70**</td>
<td>0.76***</td>
<td>0.55*</td>
</tr>
<tr>
<td>mg g⁻¹</td>
<td>ns</td>
<td>0.64**</td>
<td>ns</td>
</tr>
<tr>
<td>Mg²⁺</td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
</tbody>
</table>

*a* *P < 0.05, **P < 0.01, ***P < 0.001.
4. Discussion

Cast production and nutrient deposition were higher in this agrisilvicultural system than in other systems previously studied in the Mbalmayo Forest Reserve. Cast production at two secondary forest sites was 6.8 and 12.4 Mg ha\(^{-1}\) from mid-May to December 1994 (Norgrove et al., 1998). This may reflect differences in sites or that *T. ivorensis* plantations are conducive for earthworm activity. No comparable data on casting in tree plantations have been found. González et al. (1996) found earthworm densities were 50% lower in tree plantations than in secondary forest in Puerto Rico. Zou and Bashkin (1998) compared earthworm numbers and biomass between sugarcane fields and abandoned sugar cane fields at various times since abandonment that had either been (a) converted to eucalypt plantations, or, (b) abandoned to natural successional vegetation. Earthworms were absent in the sugar cane fields. Densities (number m\(^{-2}\)) of endogeic earthworms increased over time in both natural succession and eucalypt systems and there were no significant differences in density between systems of similar age. There were small numbers of anecic and epigeic worms in the natural succession system, but none in the eucalypt system, possibly because of the low palatability of eucalyptus litter (Lee, 1985). Gilot et al. (1995), in a pseudoreplicated experiment, compared earthworm biomass between rubber (*Hevea brasiliensis*) plantations 5, 10, 20 and 30 years of age and a secondary forest in Ivory Coast on an Oxisol. Earthworm biomass was comparable between the secondary forest, the 10 and 20-year-old plantations, with lower densities in the 5- and 30-year-old plantations. In another pseudoreplicated experiment, Mboukou-Kimbatsa et al. (1998), working in Congo-Brazzaville on coastal sandy soils, found higher earthworm biomasses in a 13-year-old *Acacia auriculiformis* plantation than in a

### Table 4
Pearson correlation coefficients between amounts of casts produced in each sampling period (Mg ha\(^{-1}\) y\(^{-1}\)) and cast nutrient and organic carbon concentrations (mg g\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Low TSD</th>
<th>High TSD</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y1</td>
<td>y2</td>
<td>y3</td>
</tr>
<tr>
<td><strong>totN</strong></td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>C\textsubscript{org}</strong></td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Ca\textsuperscript{2+}</strong></td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Mg\textsuperscript{2+}</strong></td>
<td>ns</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>K\textsuperscript{+}</td>
<td>ns</td>
<td>-0.72**</td>
<td>ns</td>
</tr>
</tbody>
</table>

\( P < 0.05, **P < 0.01, ***P < 0.001. \)

### Table 5
Amounts of nutrients and organic carbon deposited in surface casts (kg ha\(^{-1}\) y\(^{-1}\))

<table>
<thead>
<tr>
<th></th>
<th>Low TSD</th>
<th>High TSD</th>
<th>Control</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>y1</td>
<td>y2</td>
<td>y3</td>
</tr>
<tr>
<td><strong>totN</strong></td>
<td>121.1 (10.2)</td>
<td>1339.2 (102.7)</td>
<td>45.6 (4.3)</td>
</tr>
<tr>
<td><strong>C\textsubscript{org}</strong></td>
<td>94.1 (12.8)</td>
<td>1081.8 (136.8)</td>
<td>31.5 (3.8)</td>
</tr>
<tr>
<td><strong>Ca\textsuperscript{2+}</strong></td>
<td>0.086**</td>
<td>0.11**</td>
<td>0.097**</td>
</tr>
<tr>
<td><strong>Mg\textsuperscript{2+}</strong></td>
<td>177.7 (9.9)</td>
<td>1785.8 (114.7)</td>
<td>54.6 (9.9)</td>
</tr>
<tr>
<td>K\textsuperscript{+}</td>
<td>0.0047**</td>
<td>0.020*</td>
<td>0.088**</td>
</tr>
</tbody>
</table>

\( P(TSD) = 0.086, P(con v TSD) = 0.0047, P \text{ for } TSD = 0.086, P \text{ for } con v TSD = 0.0047, P < 0.05, **P < 0.01, ***P < 0.001. \)

\( P < 0.05, **P < 0.01, ***P < 0.001. \)
30-year-old secondary forest, however biomass in a 16-year-old *Pinus caribaea* Morelet plantation was lower than in the forest.

In the present experiment, slashing the plantation undergrowth and cropping significantly reduced earthworm cast production to 63% in y1, and 65% in y3, yet not significantly in y2 to 84% of the control plot levels. In an analogous experiment in a 6-year-old *T. ivorensis* plantation, activity declined to 50% of the non-cropped control (Norgrove and Hauser, 1999) in the first year. Other previous work in Mbalmayo showed a more severe decline to 25% of the forest level after burning, tillage and cropping (Norgrove et al., 1998), and similar severe declines were reported by

![Graphs showing negative power relationships between cast:soil ratio and soil concentration at 0–10 cm and 10–20 cm depths for (a) total N, (b) organic C (c) exch. Ca²⁺, (d) exch. Mg²⁺ and (e) exch. K⁺.](image)

Fig. 1. Negative power relationships between cast:soil ratio and soil concentration at 0–10 cm and 10–20 cm depths for (a) total N, (b) organic C (c) exch. Ca²⁺, (d) exch. Mg²⁺ and (e) exch. K⁺. Means of plantain mulched, plantain burned and forest control plots only. "P < 0.05, **P < 0.01, ***P < 0.001."
Cook et al. (1980) working with cowpea (*Vigna unguiculata* (L.) Walp cv. Prima) and by Hauser and Asawalam (1998) working with maize and cassava in Nigeria. In the present experiment, the land was not tilled and remained partially shaded and this might explain the less detrimental impact of cropping here. Nutrient concentrations of casts decreased from y1 to y2 in all treatments, including the control, yet remained stable from y2 and y3. In August of y1 only, the *T. ivorensis* trees were completely defoliated by an *Epicerura* sp. caterpillar (Lepidoptera: Notodontidae), however, new leaf flush occurred in late August (L. A. Norgrove, unpub. PhD thesis, London University, 1999). Thus, the nutrients in the canopy were deposited on the soil surface as nutrient-rich caterpillar frass, which may have been selectively ingested by earthworms, increasing the nutrient concentrations in the casts in y1.

The high degree of correlation of cast carbon and nutrient concentrations between years in the control plots can be interpreted as an indicator for a relatively stable system, with tree litter as the dominant input, and in which changes of conditions cause a uniform response by earthworms in relation to nutrient concentrations in their casts (Table 4). As the control system received no inputs of slash or weed residues, the amount of available food and the nutrient concentrations therein were more stable for 3 years, contributing to close correlations. On the contrary, in the low TSD, there were greater year to year fluctuations and thus fewer correlations. This might have been caused by the greater diversity of inputs. Large amounts of slash were applied at establishment and nutrients from the slash were released. Further, there was a lower nutrient uptake into tree biomass yet a higher uptake into weeds (L. A. Norgrove, unpub. PhD thesis, London University, 1999). After weeding, the fast decomposing weed residue (Norgrove and Hauser, 1999 submitted) might provide food sources, causing the worms to ingest materials of different quality and quantity than in the control, thus contributing to less strong correlations. The situation in the high TSD would have been intermediate. The relatively low level of disturbance of cropping under a higher timber stand density and the lower input of food sources from decomposing weeds apparently retain conditions.

![Figure 2](image-url)  
*Fig. 2. Relationships between total N in leaf litter and casts in y2 and y3. (a) Cast N concentration is not significantly correlated with mean leaf litter N concentration. (b) Amounts of N deposited in casts and amounts of N in leaf litter N are correlated in both y2 and y3. Means of main-plot and control treatments.*
more similar to the control and thus a higher degree of correlation.

There were marked inverse relationships between amounts of casts and their nutrient concentrations in the control plots. In cropped treatments, these relationships disappeared, presumably because of the initial application of nutrients with the slash and further fluctuations in nutrient inputs during the cropping phase, i.e. through slashed weeds and crop residues. However, the continuation of cast production, albeit at a lower level, suggests that earthworms are able to adapt to these changes in nutrient flux in their environment. Indeed, even in the low TSD cropped system, where litterfall plays a less important role, strong relationships between litterfall N input and cast N amounts persist (Fig. 2b). Zou (1993), working in tropical tree plantations in Hawaii, found that earthworm abundance was correlated positively with litterfall N content.

Ratios of cast to soil nutrient concentrations were comparable to those reported by Lal and De Vleeschauwer (1982) and Hauser (1993) on an Alfisol in south west Nigeria and by Barois et al. (1987) from south America. Cast nutrient and organic carbon concentrations were more dependent upon initial soil conditions than upon cropping or TSD treatment. The ratio of soil:cast nutrient concentrations were related by negative power functions to soil nutrient concentrations for all nutrients and organic carbon. Thus, within this range of soil nutrient concentrations, earthworms adjust to lower soil concentrations by increasing their selectivity and thus produce relatively higher quality casts on poorer soil. Hauser and Asawalam (1998) found similar relationships between cast to soil ratios and soil nutrient concentrations in short fallows and cropped fields on Alfisols in south western Nigeria.

In conclusion, the disturbance through cropping, even when nearly all trees were retained, caused a reduction in surface cast production. The reduction in cast production was less than that found in other systems without tree retention. However, the tree density to which plots were thinned and the crop management treatment had little direct impact upon cast production and nutrient turnover. Rather, initial soil chemical properties and input amounts and qualities were more important.

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References


