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Earthworm surface casting activity on slash-and-burn cropped land and in undisturbed *Chromolaena odorata* and young forest fallow in southern Cameroon

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Summary

The effect of slash-and-burn agriculture on earthworm surface cast deposition was assessed in 4–5 year old *Chromolaena odorata* (CHR) and young forest (YFOR) fallow (12–15 years) in the humid forest zone of southern Cameroon. In the villages Ngoungoumou (56.8 % forest cover), Metet (39.5 % forest cover), and Nkometou (24.9 % forest cover), plots were established in both fallow types and half were slashed, burned, and cropped in 2000, the rest maintained as undisturbed controls. In 2001, cropped plots were split, one half abandoned to fallow, the other cropped a second time as in 2000. Casts were collected weekly from April to December in 2000 and 2001.

In 2000, surface cast deposition was different between villages, in both fallow types and land-uses. At Nkometou casting was lowest and no effects of fallow type or land-use were found. At Metet and Ngoungoumou, more casts were deposited in undisturbed fallow (22.5 and 3.0 Mg ha^{-1}, respectively) than in the cropped treatment (7.1 and 0.6 Mg ha^{-1}, respectively). Cropping reduced cast deposition in both fallow types, yet more so in CHR than in YFOR.

In 2001, as in 2000, no differences were found at Nkometou. At Metet and Ngoungoumou, more casts were deposited in undisturbed controls than in the other treatments. Cast deposition was higher in plots in the first year of fallow after cropping than in double cropped plots, indicating an immediate recovery after cropping. Cast production was not correlated with soil chemical properties across villages. Earthworm species assemblages were different between villages, with large bodied, endogeic and anecic species most abundant at Metet. Earthworm species assemblage is likely to be the main factor determining surface cast deposition and thus differences between villages.

Key words: Congo basin, land use intensification, slash-and-burn agriculture, southern Cameroon

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Introduction

Tropical smallholder farming systems rely largely on biological processes of soil fertility maintenance and restoration. Earthworms can contribute to nutrient cycling and accumulation by casting at the soil surface. Earthworm casts can positively affect plant growth in the tropics (Spain et al. 1992; Pashanasi et al. 1996; Asawalam & Hauser 2001), most likely due to higher nutrient concentrations in casts than the soil (Lal & De Vleeschauwer 1982). Norgrove & Hauser (1999) showed that nutrients from casts were more available to a maize crop than those from the soil. Hauser & Asawalam (1998) and Norgrove & Hauser (2000) showed that with decreasing soil nutrient concentration the factor by which earthworms enriched the casts increased, indicating the increasing importance of earthworm surface casting with decreasing soil fertility. Thus, a high earthworm surface casting activity is desirable in low input agricultural systems to concentrate nutrients at the soil surface.

Total cast production is an indicator of burrowing and soil turnover, because 99.9 % of ingested material is egested as casts (Lavelle 1974). Norgrove & Hauser (1998) did not find sub-surface casts while sampling to 2 m depth in pits near Mbalmayo, a location not far from the villages reported upon here. Thus, it appears that surface casting alone can serve as a direct indicator of earthworm activity. Cast deposition at the surface is a viable indicator of earthworm biomass (Dash & Patra 1979).

Food crop production in smallholder systems is largely by slash-and-burn agriculture. Slashing, burning and cropping reduce earthworm density, diversity and activity (Critchley et al. 1979; Lavelle & Pashanasi 1989). In southern Cameroon and larger parts of the Congo basin, farmers maintain a mosaic of fallow types and age classes for their different crop fields. The most commonly established food crop field in southern Cameroon is a groundnut / maize / cassava intercrop, for which either 4 to 5 year old fallow, dominated by *Chromolaena odorata* or young secondary forest of 12 to 15 years is slashed and burned (Büttner 1996).

It has been shown in planted fallow systems and other researcher managed trials, that earthworms are strongly affected by the type of fallow, the biomass management system (Hauser & Asawalam 1998) and the crop cover (Norgrove et al. 1998). Little information is available on the effects on earthworm surface cast deposition, in slash-and-burn agriculture in farmers' fields of different fallow age in the Congo basin.

We hypothesize that (1) cast deposition is higher in young forest than *Chromolaena odorata* fallow, (2) clearing young forest leads to more severe reductions in surface cast deposition than clearing *C. odorata* fallow, (3) during a first year fallow, casting is higher than in a field cropped for a second year and (4) there is no effect on cast deposition of the location of the village within which these land-use changes are imposed.

Materials and Methods

Location

The experiment was established at Ngoungoumou (12°01' E, 3°18' N, Typic Kandiudox), Metet (11°45' E, 3°25' N, Typic Kandiudult) and Nkometou (11°35' E, 4°05' N, Rhodic Kandiudult), three villages in southern Cameroon, representing increasing levels of deforestation and land use intensification (Thenkabail 1999). According to Nolte et al. (2001) in the area north of Yaounde (Yaounde block), where Nkometou is located, 24.9 % of the land is under forest, 28.5 % under fallow and 26.7 % are cropped. Around Mbalmayo (Mbalmayo block), where Metet is located, 39.5 % of land is under forest, 15.8 % under fallow and 19.1 % are cropped. Ngoungoumou is represented by the southern part (Ebolowa block) of the area investigated by Nolte et al. (2001) with 56.8 % of land under forest, 10.2 % under fallow and 12.6 % currently being cropped. Due to the large number of plant species in fallows and forests it is not possible to include a botanical description of the fallow types. For details, refer to Zapfack et al. (2002), who characterized the vegetation in several villages in these three blocks. Annual rainfall in the area is bimodal. Rains start in mid-March and end in mid-July, followed by a short dry season of 6 to 8 weeks, then recommence in September and stop at the end of November. In 2000 and 2001 rainfall totals were, respectively, 1347 mm and 1114 mm in Nkometou, 1495 mm and 1265 mm in Metet, and 1456 mm and 1167 mm in Ngoungoumou.

Establishment

In each village, a 4–5 year old *Chromolaena odorata* fallow (CHR) and a 10–12 year old young forest (YFOR) were identified. Sites were selected on the basis of: size, as they were required to be at least 100 m × 25 m large; proximity of the two vegetation types; and, that the previous land use prior to vegetation succession to CHR or YFOR, was in all cases a mixed food crop field dominated by groundnut, maize and cassava. Each site was divided into 6 plots, 15 m × 15 m, located in the centre of the site and thus leaving borders up to 5 m with the bordering vegetation. Three plots were cleared and burned and 3 served as undisturbed controls. In February 2000, the CHR sites and the understorey of the YFOR were slashed. In the YFOR sites all trees were felled manually. The biomass was left to dry and burned by the end of March 2000. In both fallow types, unburned materials were piled and burned again. The 3 cropped and the 3 undisturbed plots in each site served as replicates, thus, a total of 18 cropped and 18 undisturbed control plots were established.

An intercrop of groundnut (*Arachis hypogaea* L.) local cultivar, maize (*Zea mays* L.) cultivar CMS 8704 and cassava (*Manihot esculenta* Crantz) cultivar 8017 was planted in both fallow types. First, groundnuts were seeded at approximately 20 seeds m^{-2}, by tilling the grains into the soil with hand hoes. Cassava was planted at 1.5 by 1.5 m inter and intra-row distance. Two, approximately 30 cm long, cassava sticks were planted in each hole. Two pockets of two maize seeds were planted between cassava pockets at 0.5 m distance between cassava pockets yet only in one direction of the lines. Seeding was in the second and third week of April in 2000 and the third and fourth week of April in 2001.

Measurement of earthworm surface casting

Surface casts were collected in 0.75 m × 0.75 m frames. Six frames were placed at random in each plot. All surface casts were collected from the frame once a week, beginning in April of each year. Casting stopped in December. Casts were oven-dried at 65 °C for 48 hours after each sampling and the dry weight per frame was recorded. Cast material was pooled by plot at the end of each year for analyses of texture and chemical properties.

Earthworm sampling and identification

Between May and August 1999, prior to establishing the cropped plots, five soil monoliths of 50 × 50 × 30 cm (L × W × D) were dug out in each fallow. Earthworms were hand-sorted immediately, specimens were killed in ethanol and preserved in 4 % formaldehyde solution. At about 2 m distance from each monolith, 10 liters of 0.002 % formaldehyde solution were gently poured into PVC rings of 50 cm diameter and 10 cm height. Ten minutes were allowed for the solution to infiltrate, and then worms were collected from the surface. Samples were identified at Systematic Zoology Research Group of the Hungarian Academy of Sciences at ELTE University, Budapest, Hungary. Both sample types were used to compile the species assemblage.

Soil sampling

Soil was sampled in 2001, at groundnut and maize harvest in July. Next to each of the cast sampling frames three samples of the 0–10 cm soil layer were taken and bulked. Samples were oven dried at 65 °C, then ground to pass through a 0.5 mm mesh size sieve and analyzed for pH, total N, organic C, available P and exchangeable Ca, Mg and K. Soil pH was determined in a water suspension at a 2:5 soil/water ratio. Exchangeable Ca^{2+}, Mg^{2+}, K^+ and available 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 chromic acid digestion and spectrophotometric procedure (Heanes 1984). Total N was determined using the Kjeldahl method for digestion and ammonium electrode determination (Bremner & Tabatabai 1972; Bremner & Mulvaney 1982).

Design and statistical analysis

Analysis of variance was conducted using the General Linear Model (GLM) procedure of SAS version 8. Data were analyzed in a 3-factorial design: (1) village at 3 levels, (2) fallow type at 2 levels (*Chromolaena odorata* dominated fallow 4–5 years, and young forest of 10–12 years), (3) land use at 2 levels in 2000 (undisturbed control and cropped) and 3 levels in 2001 (undisturbed control, first year fallow, and second year crop). Replicates were treated as nested within fallow types. Data were $\log_{10}(n+1)$ transformed prior to analysis. All treatment interactions were included in the model. Years were analyzed separately. Where a factor was significant, pairwise comparison of least square means of selected treatments was performed using the Pdiff option. Procedure REG was used to conduct simple and stepwise regressions between cast production and soil chemical parameters.

Results

Cast production

In 2000, the factors village and land use and all two-way interactions were significant (Table 1). All three villages were significantly different from each other in casting in the two fallow types and in cropped and undisturbed land. In Nkometou, cast production was generally very low and no effects of treatments were detected. At Metet cast production was the highest, with no difference between fallow types. At Ngoun-

Table 1. Cumulative earthworm casts (Mg ha^{-1} dry matter) deposited in three villages and cropped fields versus undisturbed controls in *Chromolaena odorata* dominated and young forest fallow, in southern Cameroon, in 2000. P values based on log-transformed data

Fallow	Village **Metet**	**Ngoungoumou**	**Nkometou**	P values **Metet vs. Ngoungoumou**	**Metet vs. Nkometou**	**Nkometou vs. Ngoungoumou**
Chromolaena	17.789	1.566	0.019	<0.001	<0.001	<0.001
Young forest	11.841	2.090	0.046	<0.001	<0.001	<0.001
Land use	**Metet**	**Ngoungoumou**	**Nkometou**	**Metet vs. Ngoungoumou**	**Metet vs. Nkometou**	**Nkometou vs. Ngoungoumou**
Undisturbed	22.488	2.970	0.035	<0.001	<0.001	<0.001
Cropped	7.146	0.648	0.030	<0.001	<0.001	0.004
Fallow	**Undisturbed**	**Cropped**	**P values**			
Chromolaena	10.584	2.332	<0.001			
Young forest	6.409	2.909	<0.001			

ns = not significant

Table 2. Cumulative amount of earthworm casts (Mg ha^{-1} dry matter) deposited in three villages and first year fallow, second time cropped fields and undisturbed controls in southern Cameroon, in 2001 (mean of *Chromolaena odorata* dominated and young forest fallow)

Land Use	Village **Metet**	**Ngoungoumou**	**Nkometou**	P between villages **Metet vs. Ngoungoumou**	**Metet vs. Nkometou**	**Nkometou vs. Ngoungoumou**
Undisturbed	18.839	1.851	0.224	<0.001	<0.001	<0.001
1. year fallow	7.702	0.684	0.134	<0.001	<0.001	ns
2. time cropping	5.422	0.112	0.103	<0.001	<0.001	ns
Fallow type	**Metet**	**Ngoungoumou**	**Nkometou**	**Metet vs. Ngoungoumou**	**Metet vs. Nkometou**	**Nkometou vs. Ngoungoumou**
Chromolaena	11.435	0.594	0.198	<0.001	<0.001	ns
Young forest	9.873	1.171	0.109	<0.001	<0.001	<0.001

CHR = *Chromolaena*, YFOR = young forest, ns = not significant goumou casting was significantly higher in YFOR (2.090 Mg ha^{-1}) than in CHR (1.566 Mg ha^{-1}, $P = 0.024$). Across villages, there were no differences in cast production between undisturbed CHR and undisturbed YFOR. However, at Metet and Ngoungoumou cropping reduced casting highly significantly ($P < 0.001$). Within each fallow type, cropping reduced casting significantly, with greater absolute and relative reductions in CHR than in YFOR. In CHR casting in undisturbed control was higher than in YFOR, while when cropped, casting was higher in CHR than YFOR ($P = 0.03$).

In 2001, the factors village and land-use and the village × fallow and village × land-use interactions were significant. The undisturbed controls were different between all three villages (Table 2). At Metet, significantly more casts were deposited in all three land-uses than at Ngoungoumou and Nkometou. Again, at Nkometou casting was lowest and no significant treatment effects were detected. At Ngoungoumou and Metet, cast production was greater in the undisturbed control plots than in the plots cropped for a second time ($P < 0.001$) and those in the first year of fallow after cropping ($P < 0.003$) and a significant recovery of casting occurred in the plots fallowed after cropping compared to those that were double cropped ($P < 0.048$). Fallow type had no effect at Metet, while in Ngoungoumou, more casts were deposited in YFOR than in CHR fallow ($P = 0.004$).

The change in casting caused by cropping compared to the undisturbed control depended on both the fallow type and the village. At Nkometou, no reduction in casting was found in the CHR fallow, yet the largest decrease in casting in the YFOR fallow (–87.5 %) compared to the other two villages (Metet –70.1 % in CHR and –55.5 % in YFOR, Ngoungoumou –98.6 % in CHR and –47.6 % in YFOR). The increase in casting in the CHR fallow (+7.5 %) at Nkometou was significantly different from all other treatments.

Relationships between soil chemical properties and cast production

Soil pH, available P, exchangeable Ca, Mg and K were significantly different between villages (Table 3). Nkometou had higher pH (6.60), available P (8.63 mg kg^{-1}), and exchangeable Ca (4.36 cmol kg^{-1}) and Mg (1.06 cmol kg^{-1}) concentrations than the other two villages. Ngoungoumou had the lowest pH (5.17), available P (5.31 mg kg^{-1}), and exchangeable Ca (2.17 cmol kg^{-1}) and Mg (0.68 cmol kg^{-1}) concentrations. Soil properties at Metet were somewhat intermediary with the exception of exchangeable K (0.107 cmol kg^{-1}) which was lower than at Nkometou (0.140 cmol kg^{-1})

Table 3. ANOVA results of soil chemical properties in three villages (village) and cropped fields versus undisturbed controls (land use) in *Chromolaena odorata* dominated and young forest fallow (fallow), in southern Cameroon, in 2001. org. = organic, av. = available, exch. = exchangeable

	pH	Total N	org. C	av. P	exch. Ca	exch. Mg	exch. K
land use	<0.001	ns	ns	ns	<0.017	<0.050	ns
fallow	<0.008	ns	ns	ns	ns	ns	<0.017
village	<0.001	ns	ns	<0.001	<0.009	<0.001	<0.034
fallow x village	ns	<0.045	ns	ns	ns	ns	ns
village x fallow x land use	ns	ns	<0.047	ns	ns	<0.021	<0.015

ns = not significant

Table 4. Earthworm species assemblages in three villages and two land use systems in southern Cameroon

Species	*Chromolaena* fallow	Young forest	Species found in only one village	Species found in only one fallow
Acanthodrilidae				
Dichogaster annae	M		M	CHR
Dichogaster bolaui	K	M		
Dichogaster ehrhardti	K G			CHR
Dichogaster gracilis		M	M	YFOR
Dichogaster kungulunensis	G		G	CHR
Dichogaster modiglianii		M K		YFOR
Dichogaster sp. nov. 1		M	M	YFOR
Eudrilidae				
Eudrilidae gen. nov.	K		K	CHR
Buettneriodrilus sp. nov. 1		G	G	YFOR
Legonodrilus sp. nov. 2	G		G	CHR
Legonodrilus sp. nov. 3	M	G		
Malodrilus buarensis	M	M K		
Malodrilus camerunensis		M	M	YFOR
Rosadrilus camerunensis	M	M	M	
Scolecillus tantillus		M	M	YFOR
Ocnerodrilidae				
Gordiodrilus sp. 1	G	G	G	
Ilyogenia sp.	M	M	M	
Nematogenia lacuum	M		M	CHR
Nematogenia panamaensis	M		M	CHR
Xibaro lavellei	K	K	K	
Xibaro sp. nov. 1	M K G	M K G		
TOTALS	8 Metet, 5 Ngoungoumou, 5 Nkometou	10 Metet, 4 Ngoungoumou, 4 Nkometou	9 Metet, 4 Ngoungoumou, 2 Nkometou	7 CHR, 6 YFOR

and Ngoungoumou (0.146 cmol kg^{-1}). Total N had a village × fallow interaction, organic C had a significant village × fallow × land use interaction.

Across villages, cast production was not correlated with any of the soil chemical properties (all $r^2 < 0.018$, all $P > 0.33$). Within Nkometou, no correlation between cast production and soil chemical properties were found. Within Metet, cast production was weakly, positively correlated with exchangeable K (Cast = 81.6 K + 1.95, $r^2 = 0.286$, $P = 0.022$). Within Ngoungoumou, cast production was weakly, positively correlated with total N (Cast = 36.1 N – 5.97, $r^2 = 0.302$, $P = 0.018$).

Earthworm species assemblages

A total of 21 species was found in the two fallow types in all three villages (Table 4). Of these, 6 are undescribed, including one new genus. Fourteen species were found at Metet and 7 species at both Ngoungoumou and Nkometou. The number of species found in YFOR and CHR were similar (14 and 15, respectively). The number of species found exclusively in one village, was 9 at Metet, 4 at Ngoungoumou and 2 at Nkometou. Thus 15 out of 21 species were site-specific. In contrast, 7 species were found exclusively in CHR, with 6 species exclusive to YFOR.

Discussion

Earthworm surface cast production was strongly affected by the site, but this observation could not be explained by soil chemical properties across sites or within sites. Hypothesis 4 has thus to be rejected. The level of deforestation was apparently not related to the levels of cast deposition. No information on earthworm surface cast production at different levels of disturbance from different sites in the humid tropics could be found. Within one site, Hauser & Asawalam (1998) reported no effects of soil chemical properties on cast production on an Alfisol in south-western Nigeria. Here, the remarkable aspect is that at Nkometou, on soil well endowed with N, P, C and basic cations and a relatively high pH, casting was lower-than in the two less fertile sites.

As the same fallow type was used and the same intercrop was planted in all three sites, it can be assumed that substrate (food) quality and availability were the same. Rainfall and its distribution did not differ profoundly between the villages. Thus, differences other than climatic and chemical conditions caused the differences in cast production. Earthworm population densities were higher at Nkometou, yet the species assemblages were not the same in all villages (Birang et al., pers. comm.). Large bodied, endogeic and anecic species were most abundant at Metet. *Rosadrilus camerunensis*, a large-bodied, probably anecic species and *Scolecillus tantillus* an endogeic species, were abundant at Metet, yet were not found in the other villages. Probably all *Dichogaster* spp. found here are epigeics thus not likely to contribute large surface casts. The species of the Ocnerodrilidae are all small-bodied endogeics (6 species), of which 4 were present at Metet (three exclusively so). Although little is known about their ecology, these differences in species assemblages may be the main reason for the large differences in surface cast deposition between villages. However, it remains to be investigated which factors are responsible for the presence or absence of certain species in certain sites.

Higher cast deposition in YFOR than CHR was only found at Ngoungoumou, thus hypothesis 1 cannot generally be accepted. Slash and burn agriculture has multiple effects on the soil and soil fauna, many of which are dependent on the scale and intensity of disturbance. Detrimental effects of slash and burn agriculture on earthworm casting were reported by Badhauria & Ramakrishnan (1989), Hauser & Asawalam (1998) and Norgrove et al. (1998). Here the effect of slash-and-burn on the amounts of casts was only significant under the medium and high casting conditions at Ngoungoumou and Metet. Considering the low casting level at Nkometou, our results do not contradict previous results. Asawalam (1997) found highly variable responses in cast production after slash-and-burn on an Alfisol in south-western Nigeria. Norgrove et al. (2003) showed that surface cast deposition after slashing *C. odorata* dominated fallow was significantly affected by biomass management (burning and mulching) yet in all cases lower than in undisturbed control.

The more severe reductions in casting in cropped CHR land than in YFOR land indicate, that either edaphic conditions in YFOR are maintained more favorably for earthworm survival and continued activity, or that the YFOR assemblages are more resilient. Hypothesis 2 was based on the expectation that in land more often cleared and with shorter phases of recovery between slash-and-burn cropping, assemblages are better adapted to the sudden change imposed. This is apparently not the case, and hypothesis 2 has to be rejected.

The recovery of cast deposition during first year fallow after cropping indicates resilience of the assemblages, as soil properties usually do not recover quickly. However, the magnitude of recovery, expressed as a percentage of the difference between undisturbed control and second year cropping, was only 16 % and 17 % at Metet and Nkometou, respectively, and 31 % at Ngoungoumou. Hypothesis 3 can thus be accepted, yet information on the time required to reach casting levels found in the undisturbed control is not available from investigations in real-time-series.

Where casting is moderate to high such as in Ngoungoumou and Metet, slash-and-burn agriculture has a negative effect on earthworm surface casting and thus nutrient cycling. However, as this effect was dependent on the fallow type and as recovery started immediately after cropping, long-term effects cannot be assessed. Thus, further research on individual factors affecting surface casting and its recovery during fallow phases is required.

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