Long-term Effects of Weed Management on Earthworm Abundance in a Banana Plantation in Davao City, Southern Mindanao, Philippines

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Abstract

Earthworm densities have been regarded as reliable indicators of soil health. A long-term field experiment was conducted in two sites (15% and 25% slope) to compare the effects of manual and chemical weeding (using paraquat and glyphosate) and determine other factors that may affect earthworm populations in a banana plantation. Based on four years of field observation, no significant difference in earthworm count between manual and chemical plots (15% slope: F-ratio: 0.96, $p = 0.43$; 25% slope: F-ratio: 14.18, $p = 0.06$) were observed. The earthworm species composition was found to differ between the two sites. The 15% site tends to have a higher earthworm population compared to the 25%-slope site, likely because of the former's higher soil organic matter content. Earthworm populations were on a declining trend in both treatments for both sites, but regression analyses show these trends to be insignificant. Rainfall, organic mulch, and weed cover were not significantly correlated with the earthworm counts. However, the declining pH in both sites could help explain the decline in earthworm populations. *Pontocolex corethrurus* showed significant avoidance response to normal glyphosate concentrations (8.055×10^{-3} mL per 350 g soil) ($p = 0.03$), but not to paraquat (1.5×10^{-3} g per 350 g soil) ($p = 0.55$). Experiments suggest that both weed management treatments do not pose a significant threat to earthworms under the conditions studied. The negative effect of declining pH needs further study.

Keywords: banana plantation; earthworm; paraquat; glyphosate; weed management

Acronyms:

ANOVA – analysis of variance
SUMIFRU – Sumitomo Fruits Corporation
OM – organic matter
RCBD – randomized complete block design

Introduction

The Philippines generates an average of US$ 400 million in annual export revenues for banana, making the country the second largest exporter in the world (Lejano, 2009). Spurred by increasing demand, many banana companies in Mindanao are on an expansion binge. In fact, banana is projected to overtake coconut oil as the country's largest export in the next three years (Macabasco, 2011). This expansion requires the use of previously undesired areas such as erosion-prone slopes for banana production. Effective farming practices are necessary to sustain production in these areas.

Effective weed management should aim to eliminate the negative effects of weeds while keeping the structure and health of the agricultural environment intact. Because some farmers use herbicides in plantations, many studies have been designed to evaluate herbicide effects and determine their possible agronomic significance by determining the amount of residues in the soil and using earthworms as useful bioindicators for soil pollution (De Andréa et al., 2003; Yasmin and D'Souza, 2010).

The ecological effect of herbicide use on soil invertebrates such as earthworms is also of interest because they are closely associated with the plant cover (Fryer and Makepeace, 1977). Earthworms are powerful regulators of soil processes, participating in the maintenance of soil structure and regulating soil organic matter dynamics (Lavelle, 1988). As soil inhabitants, earthworms are responsive to changes in the soil (pH, soil moisture, ground cover, nutrient composition, organic matter content, etc.). With their close association to plant cover, their numbers are influenced by its density and variety (Fryer and Makepeace, 1977).

This four-year study assessed the effects of weed management in a banana plantation. The study compared the effects of manual weeding employed in conventional farming and herbicide applications (i.e., paraquat and glyphosate) on earthworms in banana plantations located in 15% and 25% slopes. The study also determined the effects of weed and mulch cover, soil organic matter content, soil pH, and rainfall on earthworm populations in the banana plantation.

Materials and Methods

Location and Time of Study

The field study was conducted from December 2005 to December 2009 in the banana plantations of Sumitomo Fruits Corporation (SUMIFRU) (7°8'59.916"N, 125°22'47.239"E, 528.96 m elevation) located in Manuel Guianga, Tugbok District, Davao City, Philippines (Figure 1).

The banana plantation grows Cavendish banana, the main export fruit in the Philippines. The fields were established two to five years prior to the start of the experiment. The Caparoso Farm, where two replicates of the 15% slope site were located, had a total land area of 1.14 ha. It was previously planted with corn, upland rice, bananas (cv Binangay), tomatoes, and bell pepper. The farm started growing Cavendish banana in 2000. The Jimenez Farm, the third replicate 15%-slope site, had a total land area of 1.77 ha. It was formerly planted with coconut and coffee but were later cut and replaced with corn, peanuts, upland rice, and sweet potatoes grown in rotation. It was then converted into a banana plantation in 2000. The Bringas Farm, which was on a 25% slope, was formerly a cacao farm before converted into a banana plantation in 2003. The bananas in all the field sites were fully grown and regularly being harvested.

Field Experiments

Two experiments were conducted in the field: one each for 15% and 25% slopes and having 2 treatments and 3 replicates per treatment. The 12 plots (10 × 25 m for each replicate) were divided into 60 2-×-2-m^2 quadrats.

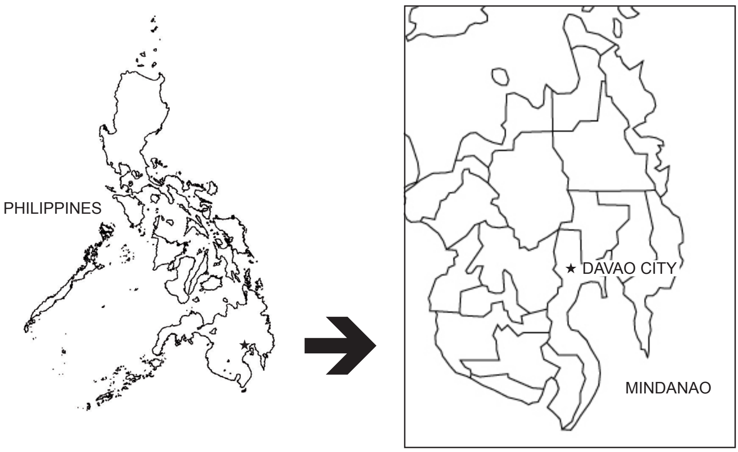

Figure 1. Map showing Davao City, Philippines

Plots were entirely enclosed in a 0.5-m hard plastic fence, which extended 15 cm below the soil surface to prevent movement of earthworms across plots. The application of treatments was done when weed cover exceeded the 30% threshold level.

Herbicide application was done simultaneously with manual weeding. Earthworm sampling was done approximately 15 days after pesticide application (Table 1). Each of the two field experiments had a randomized complete block design (RCBD) with 2 treatments (chemical weed control vs. manual weed control) and 3 replicates. Twelve random quadrats were chosen as sampling units from each replicate. There were 24 sampling dates during the 36-month data collection period. The data was analyzed using RCBD split-plot design ANOVA or repeated measures ANOVA (Jordan et al., 1999). Regression analysis was conducted to test linear relationship between month and population counts for each treatment.

Extraction and Collection of Earthworms

As a better alternative to formaldehyde, hot mustard powder was used for earthworm extraction in the field (Chan and Munro, 2001). Mustard dissolved in water emits a vapor that causes irritation to earthworms and provokes them to emerge from the soil. At each sampling, 12 quadrats per plot were randomly chosen to be applied with a 6-L mixture of 50-g hot mustard powder and water. The mixture was applied to a portion of each quadrat (1 × 1 m) slowly and gradually to allow infiltration. After identifying the worms, they were returned to the soil outside of the mustard-treated quadrats.

Analyses of Soil Samples

Soil samples were gathered from a depth of 0–10 cm and were subjected to soil analyses on the following dates: 17 January 2006, 10 July 2007, 9 January 2009, and 4 February 2010. The soil samples were submitted to the laboratory of the Bureau of Soils in Davao City. The Walkey-Black method was used to measure the organic matter content. Soil pH was determined in a 1:1 (w/v) soil and water ratio.

Results and Discussion

Earthworm Species Collected from the Sites

From February to December 2009, six earthworm species were collected from the two sites. In the 15%-slope site, the species collected were *Pontoscolex corethrurus*, *Metaphire* spp., and *Pithemera bicincta* (Figure 2); whereas in the 25%-slope site, the species were *Metapheretima* sp., *Perionyx excavatus*, and *Metaphire inflata cai* (Figure 3). All earthworm species were identified on the

Table 1. Schedule of earthworm sampling and weed management application

Year	Date		Weeding method	
	Earthworm sampling	Weed management application	Manual	Chemical
2006	27 May	03 Jun	1	1G
	01 Jul	09 Jul	1	1G
	12 Aug	15 Aug	1	1R
	23 Sept	25 Sept	1	1G
	21 Oct	27 Oct	1	1G
	02 Dec	07 Dec	1	1R
2007	13 Jan	17 Jan	1	1G
	10 Mar	26 Mar	1	1G
	21 Apr	28 Apr	1	1R
	26 May	—	0	0
	Jun	11 Jul	1	1G
	04 Aug	—	0	0
	15 Sept	26 Sept	1	0
	29 Nov	6, 8 Dec	1	1G
2008	13 Jan	—	0	0
	—	20, 22 Mar	1	1R
	Apr	—	0	0
	—	03 Jul	1	0
	—	15 Sept	1	0
	—	13, 14 Oct	1	1G
	—	10, 16 Dec	1	0
2009	18 Feb	18, 20 Feb	1	1G
	—	17, 18 Apr	1	0
	May	—	0	0
	13 Jun	—	0	0
	25 Jul	04 Aug	1	1G
	29, 31 Aug	01, 08 Sept	1	0
	Sept	—	0	0
	03 Oct	05 Oct	0	1G
	14, 21 Nov	16, 21 Nov	1	0
	—	14 Dec	1	1G
Total	24	24	23	13G, 4R

Note: G - Gramoxone (active ingredient: paraquat); R - Roundup (active ingredient: glyphosate)

Figure 2. Earthworm species found in 15% slope: (A) *Pontoscolex corethrurus*; (B) *Metaphire* spp.; (C) *Pithemera bicincta*

Figure 3. Earthworm species in 25% slope: (A) *Perionyx excavatus*, ventral side; (B) *Perionyx excavatus*, dorsal side; (C) *Metaphire inflata cai*; (D) *Metapheretima* sp.

first year of the study with the assistance of Dr. Nestor Baguinon, a professor from the University of the Philippines Los Baños. For identification, the study used a dichotomous key published by Michaelsen (1903) and consulted other identification keys by Michaelsen (1900), Gates (1972), and Sims and Easton (1972).

Effect of Weed Management Practices at the 15%-slope site

Earthworm counts in the 15%-slope site were found not to be significantly affected by weed management practices (Table 2).

Counts of the dominant species *P. corethrurus* tended to be higher in the manual plots than in the chemical plots for the 15%-slope site. The opposite is true for *P. bicincta*, whose counts tended to be higher in chemical plots. However, the differences between the sampling sites were not statistically significant. On the other hand, not much difference was found in the earthworm counts of the less dominant species *Metaphire* spp.

In both sites, the endogeic species were the most dominant. *P. corethrurus* (125.71±2.23) had the highest adjusted population count followed by *P. bicincta* (114.00±1.66). As endogeic earthworms, they greatly contribute to

Table 2. The adjusted population counts of earthworm species and categories in manual and chemical weed management systems under the 15% and 25% slopes

Species/Category	Manual	Chemical	P-value
15% slope			
Pontoscolex corethrurus	127.40±3.61	124.03±3.12	0.39
Pithemera bicincta	112.98±2.21	115.40±2.60	0.49
Metaphire spp.	103.26±1.31	103.05±1.08	0.77
Immature (no clitellum)	122.92±2.93	122.31±3.27	0.75
Mature (with clitellum)	109.02±1.65	108.90±1.55	0.93
Total	108.70±1.49	107.59±1.35	0.43
25% slope			
Metaphire inflata cai	115.29±2.31	114.62±2.34	0.46
Metapheretima sp.	104.99±1.31	101.33±0.64	0.02*
Perionyx excavatus	104.92±1.22	103.74±1.09	0.34
Immature (no clitellum)	118.84±3.11	115.39±3.24	0.34
Mature (with clitellum)	105.19±1.13	103.83±1.03	0.02*
Total	106.60±1.20	104.24±1.17	0.06

Note: Each value in the table represents the mean±std error of 24 sampling dates, 2 treatments, 3 replicates, and 12 samples from each replicate.
* Significant at 0.05

root decomposition, soil profile mixing, and aeration by burrowing (Werner, 1990). Endogeic earthworms significantly modify soil aggregation and over-all soil porosity, which in turn control water flow in soil (Bottinelli et al., 2010). In a study which determined the influence of agricultural land use on the size and composition of earthworm in South Africa, *P. corethrurus* was also the most abundant (Dlamini and Haynes, 2004). *P. corethrurus* proved to be well adapted to human-disturbed areas, contributing the highest earthworm density in residential, agricultural, grassland, and forest plantation areas (Somniyam and Suwanwaree, 2009). The higher number of *P. corethrurus* in manual plots could possibly have been caused by the more frequent, repeated applications of paraquat, which might have caused its accumulation in the soil. Paraquat has been reported to significantly reduce cocoon production ($p < 0.01$) and hatching of juveniles ($p < 0.05$) at 1000 $mg{\cdot}kg^{-1}$ of soil (Van Gestel et al., 1992). But this is more than the expected concentrations following recommended application rate of paraquat (1.12 $kg{\cdot}ha^{-1}$), which is probably why this difference is not significant.

For both treatments, the population count of *Metaphire* spp., although also an endogeic species, was low compared to other earthworm species found in the 15%-slope site. This can be attributed to the worm's very large size (approximately 1 cm in width and 26–30 cm in length). Studies reveal that bigger earthworms are found deeper in the soil (Jiménez and Decaëns, 2000).

In both sampling sites (15% and 25% slopes), although immature population counts were higher compared to the mature counts, the numbers were not significantly different (15% slope: $p = 0.182$; 25% slope: $p = 0.076$). Jiménez and Decaëns (2000) reported that juveniles live closer to the surface than mature individuals or nearly mature worms because cocoons are laid closer to the soil surface where juveniles hatch. Also, the weak burrowing ability of juveniles compared to adults limits their vertical distribution to the upper horizons of the soil. Therefore, immature worms are easily reached by the vermifuge and extracted, contributing to the high population counts in both sites. On the other hand, the lower counts of mature worms can be attributed to the fact that they burrow deeper into the soil (Jiménez and Decaëns, 2000), which the vermifuge is not able to reach.

Earthworm counts in both treatments for *P. corethrurus* and *P. bicincta* were decreasing over time while that of *Metaphire* spp. was increasing. The counts for mature and immature worms for both treatments were also decreasing over time. However, regression analyses ($p > 0.05$) show no significant decline of earthworm counts in the 15% slope over time.

Effect of Weed Management Practices at the 25%-slope Site

Weed management practices did not significantly affect immature counts, but mature counts were significantly higher in the manual plots than the chemical plots (Table 2). However, the total earthworm counts for the 25% slope were still insignificant between manual and chemical plots. When individual species were considered, there was a significant reduction in the population of *Metapheretima* sp. due to chemical weed management. On the other hand, there was not much difference found in the earthworm counts of the dominant species *M. inflata cai* in both treatment plots in the 25%-slope site. The same is true for the less dominant species *P. excavatus* also found in the 25% slope.

For the 25% slope, *M. inflata cai* (mean = 114.96±1.61), an endogeic species, had the highest adjusted population count. Epigeic species such as *P. excavatus* (mean = 104.33±0.81) and *Metapheretima* sp. (mean = 103.16±0.73), both found in the 25% slope, had lower population counts.

Epigeic worms are not usually found in soils with low surface organic matter (Soil Quality Institute, 2001). Also, their very behavior as topsoil dwellers exposes them to climatic fluctuations and predator pressures, reducing their numbers. They only retreat to the soil when avoiding dry or hot conditions in the surface litter (Werner, 1990). As a result, epigeic species usually would not be found in the soil except as transients (Wood and James, 1993). Although *P. excavatus* is known to survive in many different kinds of climates more than any other earthworm species (Gates, 1972) due, probably, to its remarkable regenerative capacity, it requires considerable moisture and organic matter to survive (Blakemore, 1994).

Studies have shown that repeated applications of glyphosate increases the metabolites of the chemical in the soil and increase its half-life values, which make the metabolism of such substance through microbial activity difficult (De Andréa et al., 2003; Springett and Gray, 1992). However, glyphosate was only applied four times during the period of observation reported here (Table 1). Although paraquat was more frequently applied in the field than glyphosate, the field's conditions contribute to the rapid deactivation and short half-life of the chemical.

Thus, it can be implied that the application of these chemicals may have no direct effect on the population of *Metapheretima* sp. in the 25% slope. *Metapheretima* sp., due to its epigeic nature, prefers high-quality surface litter, which might have caused its disappearance. Hairiah et al. (2001) reports the disappearance of epigeic species *Metapheretima carolinensis* in North Lampung, Indonesia, due to the conversion of the forest to agricultural land utilized for continuous maize monoculture cropping system.

Glyphosate may have also elicited avoidance responses from *Metapheretima* sp. populations, which in turn may have indirectly contributed to the statistically significant difference in the population counts obtained from the chemical plots. The avoidance response of earthworms to soil contaminants (i.e., herbicides) tends to increase susceptibility to indirect sources of mortality such as predation, UV radiation, and/or desiccation (Verrell and Buskirk, 2004). For instance, Keogh and Whitehead (1975) reported in their study a similar avoidance response of earthworms to contamination of benomyl (a fungicide), which resulted to the reduction of earthworm numbers in their experimental sites due to increased emigration from contaminated areas. This emigration in turn caused a localized reduction in surface casting and increase in leaf litter accumulation in their experimental sites.

The use of herbicides in weed management entails minimal soil disturbance caused otherwise by tillage and manual weeding in agricultural soils, thus preventing adverse results of soil erosion. The environmental impact of herbicides in general depends on its degradation rate and mobility in the soil (Amondham et al., 2006). Apparently, neither of the two herbicides used in the study had any significant impact on the earthworm populations. The lack of significant difference in the earthworm counts between manual and chemical weeding was because paraquat deactivation was favored by the tropical temperature and clay type of soil (with high organic matter) within the banana plantation site; it can also be attributed to the influence of temperature and soil pH and microbial activity on glyphosate's degradation kinetics. The release of glyphosate from the soil particles increases as temperature increases (Eberbach, 1998).

Earthworm counts in both treatments for *M. inflata cai* and *Metapheretima* sp. were decreasing over time while that of *P. excavatus* was increasing. The counts for mature and immature worms for both treatments were also decreasing over time. However, these trends were not significant ($p > 0.05$).

The total population counts found in the 15%-slope site (mean = 108.14±0.95) was higher compared to the population counts of worms collected from the 25% slope (mean = 105.42±0.78). This is consistent with the observations made by Suárez et al. (2006), who found that slope was one of the significant predictors of earthworm presence. They suggested that areas close to agricultural clearing and located towards gentler slopes or valley bottoms are very likely to support exotic earthworms. However, exotic earthworms were less likely to be found on steeper slopes and locations in the core of extensive forest landscapes (Suárez et al., 2006).

Differences between earthworm counts due to treatment, on the other hand, show no significant differences, which may be explained by the weed management systems employed. Aside from weed management, earthworm abundance in agricultural areas could also be influenced by the equilibrium of soil environmental factors that include organic matter (food resource), soil pH, moisture-holding capacity and internal drainage, rainfall and temperature, predation and parasitism, as well as earthworm introduction (Soil Quality Institute, 2001). Changes among these important factors influence the changes of earthworm abundance over time.

Effect of Ground Cover

Spatial and temporal variation in earthworm populations can occur on the basis of both abiotic and biotic factors. Abiotic factors include resource availability, soil type, temperature, and moisture regimes (Edwards and Bohlen, 1996; Curry and Schmidt, 2007), which are influenced by ground cover. In turn, earthworm communities are known to affect ground vegetation through their effects on litter thickness, recycling of nutrients, seed dispersal, and physical features of the germination niche (Thompson et al., 1993).

The organic mulch produced from banana litter provides physical protection for the soil and provides a favorable environment for the soil fauna. There was no significant correlation ($p < 0.05$) between earthworm counts, on one hand, and mulch, weed, and total ground cover, on the other hand, in both manual and chemical plots from the two sites (Table 3).

Weed, mulch, and total ground cover were not significantly correlated ($p > 0.05$) to earthworm populations and, thus, cannot explain its variations over time. However, weed cover was significantly higher ($p < 0.05$) in the chemically treated plots in both sites. This was due to the relaxation of herbicide application in certain months during the second, third, and fourth years of sampling. Mulch cover was also significantly higher ($p < 0.05$) in the manual plots of the 15%-slope site but was not significant for the 25%-slope site ($p > 0.05$).

Although the weed cover tends to be higher in manual plots than in the chemical plots, it can be compensated by the higher mulch cover in the chemical plots. The total ground cover, however, was significantly higher ($p < 0.05$) in the chemical plots. The moist and cool environments that earthworms

Table 3. Correlation between ground cover and earthworm population

Test of significance	Mulch cover		Weed cover		Total ground cover (mulch + weed)	
	Manual	Chemical	Manual	Chemical	Manual	Chemical
15% slope						
Pearson correlation	–0.71	–0.05	0.21	–0.07	0.10	–0.12
Significance (two-tailed test)	0.75	0.83	0.33	0.74	0.66	0.59
25% slope						
Pearson correlation	–0.12	0.07	0.28	–0.14	0.15	–0.07
Significance (two-tailed test)	0.58	0.76	0.20	0.53	0.49	0.76

prefer was generally found under the canopies of the banana plantation regardless of mulch and weed cover. Therefore, earthworm populations did not significantly differ between treatments.

Effect of the Sampling Period

The effect of month of sampling on earthworm counts was significant for all species and categories (mature and immature) found on both the 15%- and 25%-slope sites ($p > 0.05$). However, rainfall was not significantly correlated with the earthworm counts over the sampling period ($p < 0.05$).

The nonsignificant correlations between rainfall and earthworm counts indicate that other factors aside from rainfall contribute to the variation of earthworm counts obtained over time. Rainfall data may not also be related to soil moisture at the time of sampling. Soil moisture is an essential factor that determines the degree of activity and location in the soil profile of earthworms since they are animals with cutaneous respiration (Lavelle, 1988; Lee, 1985).

Effect of Organic Matter and pH

The Walkey-Black method was used to measure the baseline of organic matter (OM) content of the soil at the start of the experiment, the OM content after a year, a year and a half, 3 years, and 4 years. The soil OM levels were tested on the following dates: January 2006, July 2007, January 2009, and February 2010.

Organic matter was higher in the 15% slope likely because it is an older banana farm. However, the general trend is that organic matter increased over time in both sites (Table 4). The differences in percent OM values across treatments were not significant in both sites ($p < 0.05$).

Earthworms affect soil organic matter dynamics and soil aggregation. For instance, earthworm activity plays a significant role in both acceleration

Table 4. Percent organic matter of the soil from 15% and 25% slope sites

Treatment	January 2006	July 2007	January 2009	February 2010	Grand mean
15% slope					
Manual	3.85	4.67	4.58	4.51	4.40
Chemical	4.00	4.28	4.46	4.4	4.29
25% slope					
Manual	3.13	2.86	3.34	3.22	3.14
Chemical	2.80	2.93	3.48	3.29	3.13

Note: Mean of organic matter is the average organic matter content of the soil obtained from 6 replicates (3 replicates per treatment) per slope.

of decomposition and mineralization processes (C loss) and in storage of carbon or C-accumulation in stable aggregates (Brown et al., 2000). Coq et al. (2007), in a study that aimed to characterize the effects of an endogeic worm *P. corethrurus* on soil aggregation and SOM dynamics, found that the casting activity of earthworms increased the proportion of soil aggregates and, thus, the enrichment of cast in carbon. In addition, the casts, compared to the non-ingested soil excreted by the earthworms, increased mineralization. This indicates a higher microbial activity and enrichment of biologically active compounds.

Soil organic matter plays a central role in the functioning of ecosystems and is beneficial from an agronomic and environmental points of view. Alternative cultural systems that enhance carbon (C) sequestration in agricultural soils lead to an increase in soil macrofauna (Coq et al., 2007). In a study aimed to test the effect of organic matter on two earthworm species, *Diplocardia ornata* and *D. smithii*, organic matter removal decreased the average individual biomass of both species (Jordan et al., 1999).

Table 5 shows the levels of soil pH recorded on January 2006 and 2009, July 2007, and February 2010. The differences in soil pH were not significant in both sites ($p > 0.05$).

The size of earthworm population depends on a wide range of factors that includes the soil pH (Edwards, 1998). Soil pH tolerance ranges vary among earthworms species. This may explain why higher population counts were found on the 15%-slope site than the 25%-slope site since the dominant species *P. corethrurus* is able to tolerate acidic soils. Meanwhile, epigeic earthworms are somehow resistant to changes in soil pH because it is a nonburrowing species that feed and remain on surface litter found on the soil (Raty and Huhta, 2003). Finally, anecic species are highly sensitive to acidic soil (Raty and Huhta, 2003); however, no anecic species were found in the field.

Table 5. Soil pH values measured from the 15% and 25% slope sites

Treatment	January 2006	July 2007	January 2009	February 2010
15% slope				
Manual	5.55	5.69	5.33	4.97
Chemical	5.36	5.09	4.97	4.86
25% slope				
Manual	6.80	6.56	6.42	6.11
Chemical	6.64	6.74	6.46	6.05

Note: Mean of soil pH is the average pH the soil obtained from 6 replicates (3 replicates per treatment) per slope.

Generally, the soil pH of both the 15%- and 25%-slope sites tended to become more acidic over time. Changes in soil pH might have been the primary reason why there were declining trends in earthworm populations in both sites, even though these differences were not significant.

In general, earthworms do not thrive in soils with pH below 5.0 (Edward and Lofty, 1972; cited in Soil Quality Institute, 2001). Soil pH may affect the survival of adults and, thus, production of juveniles (Amorim et. al, 2005). Soil pH has been established to reduce the number of earthworm casts, which consists of waste excreted after feeding and are composed mostly of soil mixed with digested plant residues and is essential for soil aggregation (Baker et al., 1995).

The decrease in soil pH can occur under natural conditions over thousands of years, with high rainfall areas most affected. However, soil acidification can happen rapidly over a few years under intensive agricultural practices, which include application of ammonium-based nitrogen fertilizers to naturally acidic soils in excess of plant requirements, leaching of nitrate nitrogen (originally from these fertilizers) out of the root zone, and continued removal of alkaline plant and animal produce and waste products from the agricultural area. Acidification can affect either the surface soil only or both the surface and subsoil (Moody, 2006).

Conclusion

The earthworm species found in the 15% slope were different from those found in the 25% slope. *P. corethrurus*, *P. bicincta*, and *M. inflata cai*, the endogeic species found in both slopes, were easier to extract.

The differences in the earthworm population counts under contrasting weed management systems (manual vs. chemical) in both sampling sites were not significant. The exceptions were *Metapheretima* sp. and total mature counts for 25% slope, which showed significantly lower counts under chemical weed management. This was likely because of the avoidance behavior response of earthworms to the herbicides, which in turn exposed these worms to predation and other mortality factors. Toxicity is a less likely cause since normal rates of herbicide application in the field are far from LC_{50} values that can affect survival, growth, and reproduction of earthworms. The possibility of accumulation of both paraquat and glyphosate is neglected because of their short degradation half-lives, which are facilitated by tropical conditions.

The correlation coefficients between mulch, weed, and total ground cover and rainfall, on one hand, and earthworm counts, on the other hand, were generally not significant, possibly suggesting that the range of values obtained for the parameters were not sufficient to influence earthworm populations. While earthworms generally prefer a moist and cool environment, this was generally obtained under the canopies of the banana plantation regardless of mulch and weed cover.

Soil organic matter and pH were not significant across treatments. Soil organic matter content may have contributed to the higher population counts of earthworms in the 15%-slope site. But this soil variable could not explain the declining earthworm populations in both sites. Soil pH is a more likely explanation for the declining trend of earthworm populations, considering that acidic soil is generally unfavorable to earthworms. Both the 15%- and 25%-slope sites showed a declining trend in soil pH, making it acidic, and the rates of decline were almost similar, following the trend of earthworm populations.

The results of this field survey indicate that both weed management treatments do not pose a significant threat to earthworms inhabiting these agroecosystems. But further studies should be conducted to confirm if pH is indeed related to the decline of earthworm populations in the field as the results suggest.

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