Impacts of Long-term Weed Management on the Diversity and Abundance of Grasses in Banana Plantation Slopes in Davao City, Philippines

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Abstract

Banana is one of the main export products in the Philippines. The growing demand for banana products generates a need for plantation expansion even in erosion-prone areas like slopes. Effective farming practices in slopes are therefore needed to conserve the soil and establish a sustainable production. One of these systems is weed management, which is a critical component of farming practice in sloping lands. A 3-year study was conducted to compare manual and chemical (paraquat and glyphosate) weed management on the abundance and diversity of grasses in a banana plantation. Counts, biomasses, seed bank, and diversity indices of grasses were compared in identical experiments in 15% and 25% slopes. From the seed banks, 7 grass species were observed: *Cyperus brevifolius*, *Cynodon dactylon*, *Eleusine indica*, *Imperata cylindrica*, *Paspalum conjugatum*, *Digitaria ciliaris*, and *Digitaria longiflora*. Generally, there was a decreasing trend in the seed bank counts in both manual and chemical plots of 15% and 25% slope. However, the differences between treatments were not significant. Chemical treatments reduced the general counts and biomass of monocot weeds, but this effect was generally not significant. Chemical treatments significantly reduced the counts of *P. conjugatum* in 15% slope and the biomass of *E. indica* in 25% slope in the field. *C. dactylon* was found to be the dominant species in the field because of its early establishment in the slopes, its spreading growth and its allelopathic properties, which suppressed other species. There was a significant increase in diversity in both treatments on two slopes, but chemical plots had a significantly higher diversity compared to the manual plots. Chemical weeding was also less expensive and less laborious than manual weeding.

Keywords: banana plantations; grasses; weed management

Abbreviations:

ANOVA – analysis of variance
RCBD – randomized complete block design

Introduction

The banana industry in Mindanao is continuously growing and dominating in terms of value and production (Martin, 2006). The growing demand for banana products generates a need for plantation expansion even in erosion-prone areas like slopes. Effective farming practices are therefore needed to conserve the soil and establish a sustainable production system in this environment. One of these systems is weed management, which is a critical component of farming practice, especially in sloping lands where utilization of certain weeding methods can aggravate soil erosion.

The loss of topsoil and organic substances as a result of soil erosion leads to reduced soil quality (Baldwin, 2006) and subsequent decline of the quality of the crop. A vegetative cover, such as grasses, can absorb the impact of raindrops on the soil and prevent erosion (Brady, 1974). Its root system increases the stability of soils on slopes by anchoring the soil mass into the bedrock and providing interlocking fibrous binders within the soil mass (Ziemer, 1981). However, the presence of such vegetation poses a threat to the crops since it grows abundantly and competes with the crops for nutrients and water and acts as breeding grounds for pests apart from impeding normal activities (Srinivasan, 2003). Because these weeds can reduce yield and income of farmers, 50% of production costs in banana plantations is allotted for weed control (Hammerton, 1981).

The adverse effects of weed in agriculture stimulated the need to devise various physical and chemical methods to control them. In banana plantations in the Philippines, conventional manual weeding practices include manual pulling, hoeing, tilling, plowing, and mulching. Although they can control certain weeds, doing so is costly and time- and energy-consuming, especially when applied in large farming areas (Srinivasan, 2003). Manual weeding is also not applicable for sloping areas since they disturb the soil and make it vulnerable to erosion. This generates the need to adapt alternative weed management methods such as the use of broad spectrum herbicides.

Chemical weed control makes use of herbicides like glyphosate and paraquat. Paraquat is a contact, nonselective, and nonsystemic herbicide that acts on the point of contact on the green part of the plant, thus keeping the roots intact to bind the soil and prevent soil erosion (Srinivasan, 2003). On the other hand, glyphosate is a nonspecific and systemic herbicide, which is translocated in a source-to-sink pattern from the point of contact (Preston and Wakelin, 2008). It kills the whole weed including its underground parts by blocking the shikimate pathway which is important for biosynthesis of aromatic amino acids needed for plant growth (Baerson et al., 2002). Weed suppression using herbicides, rather than their complete eradication, helps prevent soil erosion (Aldrich and Kremer, 1997). In a study conducted in banana plantations in Costa Rica, herbicides had the least impact on analyzed biological indicators among the crop protection products they have tested (i.e., fungicides, insecticides, and nematicides). Furthermore, contact (paraquat) and systemic (glyphosate) herbicides did not have any effect on biological structure and stability of communities within and adjacent to banana plantations (Vargas, 2006).

The manual weeding methods used in this study are those that are conventionally practiced in banana plantations in the Philippines, such as ring weeding, manual slashing, and mechanized grass cutting. This study is also only limited to grasses; however, a separate study on dicots had been conducted. There were seven dominant grass species in the sampling sites: *Cynodon dactylon*, *Cyperus brevifolius*, *Eleusine indica*, *Imperata cylindrica*, *Paspalum conjugatum*, *Digitaria ciliaris*, and *Digitaria longiflor*a.

C. dactylon, is a perennial grass that occurs throughout the semi-arid, tropical, and subtropical regions of the world (Rao, 2000). This weed grows extensive rhizomes, long runners, and roots at nodes (Stone, 1970). This species can complete its life cycle, from germination to seed production, in around four months and can produce up to 230 seeds per panicle during the first three months following the initiation of seed set (Perez and Labrada, 1985). A study of *C. dactylon* in Cuba showed that its seeds germinate 23 days after sowing and it flowers 67 days after germination with vigorous growth observed during rainy seasons (Perez et al., 1981). Its extensive growth through rhizomes and runners and high production of seeds make it competitive against crops and other weeds in an area.

C. brevifolius is a perennial weed that grows all year round in tropical regions both in rainy and dry seasons (Rodiyati and Nakagoshi, 2003). It forms mats of reddish brown rhizomes that can reach up to 20 cm in length (Galinato et al., 1999). It produces more flowers during the rainy season and forms tillers during drought as a survival strategy, which makes it persistent as a weed during adverse conditions (Rodiyati and Nakagoshi, 2003). This weed spreads and grows rapidly. Once its growth is established, it is difficult to eradicate (Rodiyati and Nakagoshi, 2003), but it can be controlled chemically 20 to 30 days after emergence (Galinato et al., 1999).

E. indica, known as goosegrass, is an annual or perennial grass that grows up to 30 to 45 cm tall (Rao, 2000). It is a tufted weed with a culm that reaches 0.6 m tall. Hoeing and cultivation effectively controls young plants (Galinato et al., 1999). However, established weeds are difficult to remove due to their dense root system. They are chemically controlled through preemergence or post-emergence treatments 15 to 25 days after emergence (Galinato et al., 1999). Paraquat is only partially effective in controlling this grass. The grass may show scorching after treatment but can recover immediately after spraying (Rao, 2000).

I. cylindrica, known as cogon grass, is an erect perennial grass that can grow to a height of 60 to 120 cm. This species grows well in soils of low and high fertility and can persist even in drought conditions. It is difficult to control *I. cylindrica* by mechanical methods, but these may help in reducing the infestation of the grass (Rao, 2000). Frequent cultivation can control the weed specifically when rhizomes are exposed to desiccation (Galinato et al., 1999). Paraquat kills the aboveground parts of the weed and allows regeneration through rhizomes after one to three weeks. On the other hand, glyphosate gives a permanent control of the weed by also killing its rhizome (Rao, 2000).

P. conjugatum, known as "carabao grass," is a perennial grass that reproduces by seeds and runners and spreads quickly within an area by means of stolons (Rao, 2000). It is difficult to control by mechanical means once established. Paraquat gives an immediate control of the weed but allows its regeneration after three to four weeks. On the other hand, glyphosate completely controls this plant since it acts on the underground organs of the plant (Rao, 2000).

D. ciliaris and *D. longiflora*, both known as crab grass, are important weeds of rice. Seeds of both species germinate in January to early April (Elmore, 2008) at 25–35 °C at day and 15–25 °C at night (Chauhan and Johnson, 2008a). *D. ciliaris* is a warm season annual plant (Beck et al., 2007). Its germination is low at 25 °C at day and 15 °C at night (Chauhan and Johnson, 2008a). It grows shoots in late July and August (Elmore, 2008). The depth of the seed in the soil affects the germination. Two cm burial of *D. longiflora* seeds and 8 cm burial of *D. ciliaris* seeds inhibited emergence (Chauhan and Johnson, 2008a).

The study aimed to compare the long term effects of the manual weeding practices (ring weeding, manual slashing, and mechanized grass cutting) and chemical weed control (using glyphosate and paraquat) in 15% and 25% slopes, looking at (1) field counts, biomass, and seed bank counts of five dominant monocot weed species present in a banana plantation; (2) species composition and diversity of dominant monocot species; and (3) weed management costs.

Materials and Methods

Time and Place of Study

The field study was performed in the banana plantations of Sumitomo Fruits Corporation located in Guianga (7006'29.83" N, 125024'48.58" E, 528.96 m elevation), Tugbok District, Davao City (Figure 1) from January 2006 to December 2008.

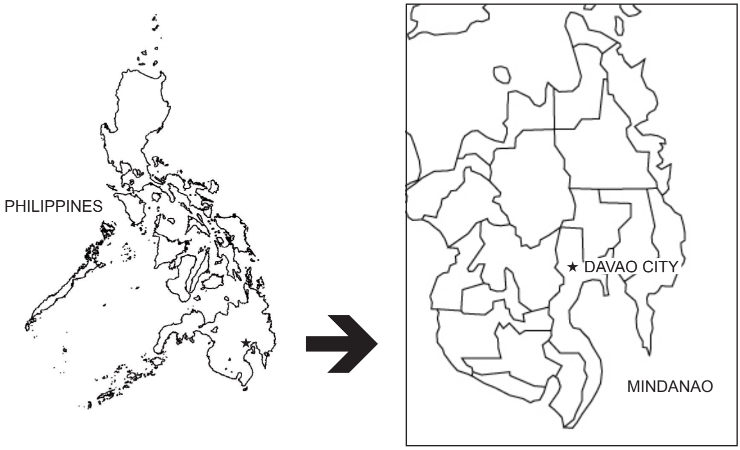

Figure 1. Map showing the location of Davao City, Philippines

Field Experiment

Two identical experiments were conducted in two slope conditions: 15% and 25%. In each slope condition, two treatments (manual and chemical), with three replicates, were laid out using randomized complete block design (RCBD). For the 15% slope, two replicates was situated in the Caparoso Farm with an elevation of 651 to 700 m. ASL and one replicate in Jimenez Farm with an elevation of 601 to 650 m ASL. The three replicates for the 25% slope were situated in the Bringas Farm, with an elevation of 501 to 550 m ASL. The 15% plots started planting Cavendish bananas in 2000. Caparoso farm was previously planted with corn, upland rice, tomatoes, bell peper, and non-Cavendish bananas. Jimenez farm was formerly planted with coconut, coffee, peanuts, upland rice, and sweet potatoes. All the replicates in 25% slope was previously planted with cacao and only started planting Cavendish bananas in 2003. The bananas in all these sites were randomly arranged. Each plot covered an area of 10 × 25 m, equally divided into sixty 2-×-2-m quadrat for sampling purposes.

Each experiment had two treatments: manual weeding and chemical weed control. Three weeding techniques were used in manual plots: ring weeding by manual slashing around small plants; mechanized grass cutting in the main and secondary canals; and manual slashing and hand weeding within the rows when the banana canopy closed.

Chemical weed control consisted of cyclic application of paraquat at monthly intervals for two months followed by glyphosate on the third month (Table 1). The sites were treated monthly due to the high coverage of grasses and broadleaves. However, application interval was later adjusted to become less frequent to allow weed regrowth. Each application of paraquat (Gramoxone™)

Table 1. Schedule of weed sampling and weed management within corresponding type of treatment

Year	Weed sampling date	Management application date	Treatment	
			Manual	Chemical
2006	January 28	February 2	1	1G
	March 11	March 15	1	1G
	April 27	April 29, 30	1	1R
	May 27	June 3	1	1G
	July 1	July 9	1	1G
	August 12	August 15	1	1R
	September 23	September 25	1	1G
	October 21	October 27	1	1G
	December 2	December 7	1	1R
2007	January 13	January 17	1	1G
	-	February	0	0
	March 10	March 26	1	1G
	April 21	April 28	1	1R
	May 26	June 2	0	0
	July 5	July 11	1	1G
	August 4	August 12	0	0
	September 15, 22	September 26	1	0
	November 29	December 6, 8	1	1G
2008	January 12	January 17	0	0
	March 8, 15	March 20, 22	1	1R
	May 10, 21	May 31	0	0
	June 21, 28	July 3	1	0
	August 2, 4	August 7	0	0
	September 6, 13	September 15	1	0
	October 11	October 13,14	1	1G
	December 8, 15	December 10, 16	1	0

Notes:
0= no manual weeding due to a very low weed population
1= paraquat was applied as Gramoxone™ (G), gylphosate as Round-up™ (R)

or glyphosate (Roundup™) had 120 mL (paraquat or glyphosate) per 16 L of water, which was equivalent to active ingredient concentrations of 120 $g \cdot ha^{-1}$ paraquat and 600 $g \cdot ha^{-1}$ glyphosate.

Counts and Biomass of Grass Weeds

Counts of grass species was obtained from the six sample quadrats. The number of plants of each grass weed species per quadrat was taken one week before the monthly application of weed treatments.

The biomass of grass weed species counted from the sample quadrats was determined. The samples were sun dried in the plastic rain shelter for one week and then oven dried for 24 h at 80 °C and weighed.

Seed Bank Sampling

Soil samples were taken for seed bank count twice every year. Six random sample quadrats were used for sampling in each treatment plot. Different quadrats were used at each sampling dates. Soil samples were obtained at a depth of 5 cm using a cylindrical soil core (7 cm in diameter) from ten random points arranged in a Z-shape manner per quadrat. From each quadrat, soil samples were pooled and spread evenly on plastic trays. The trays were set up in the plastic rain shelter under natural light conditions. The trays were rotated once a week to limit differences in light conditions. The trays were regularly watered. They were checked daily in the first four weeks for new seedlings and once a week thereafter. The seedlings were counted and then removed from the tray to allow emergence and growth of other seedlings. The number of individual seedlings for each grass weed species and the date of its emergence were recorded.

Index of Species Diversity

The index of diversity was calculated based on field counts to determine the effect of the two weed management methods on the diversity, succession, and dominance of the grasses and sedges in the field. Among the different measurements for diversity, Shannon-Wiener index of diversity (H') was used in this study due to its sensitivity to common and rare species in evaluating diversity (Setala, 2006). In addition, the index takes into account the number of species (richness), as well as the abundance of each species (evenness). The index of diversity is calculated as follows:

$$H' = -\Sigma\, p_i \ln p_i$$

Where p_i is the proportion of the *i*th species, ln as the natural logarithm of a number, n_i as the number of individual in the ith species, N as the total number of individuals, and s as the total number of species.

Weed Management Cost

The two weed management treatments over the 3-year sampling period was compared in terms of labor requirements, labor cost, and the number of weed management applications.

Statistical Analysis

Data on count, dry weight, and seed bank of the monocot weed species were log (x + 1) and square root (x + 10) transformed and were analyzed using repeated measures ANOVA of a RCBD analysis with data obtained over time with subsampling. Mean separation used the least significance difference test at 0.05 level of significance. CropStat 7.2.3 were used for analyses.

Results and Discussion

Seed Bank

Seven monocot weed species were identified as follows: *Cyperus brevifolius*, *Cynodon dactylon*, *Eleusine indica*, *Imperata cylindrica*, *Paspalum conjugatum*, *Digitaria ciliaris*, and *Digitaria longiflora*.

In both 15% and 25% slopes, there were relatively more weeds present on manual plots than in chemical plots (Table 2). However, the differences were not significant with exception to *C. dactylon* in 15% slope. *C. dactylon* have significantly lower seed bank counts in chemical plots than in manual plots. This could be due to the effectiveness of herbicides in controlling the species. Glyphosate effectively controls perennial weeds like *C. dactylon* (Rao,

Table 2. Counts log of monocot seedling emergence in seed banks under two weed management treatments (manual and chemical) in 15% and 25% slopes

Species	15% slope		25% slope	
	Manual	Chemical	Manual	Chemical
Cyperus brevifolius	0.19 ± 0.05	0.15 ± 0.05	0.14 ± 0.06	0.11 ± 0.06
Cynodon dactylon	0.22 ± 0.09[a]	0.14 ± 0.07[a]	0.20 ± 0.09	0.15 ± 0.07
Eleusine indica	0.22 ± 0.07	0.26 ± 0.08	0.24 ± 0.08	0.21 ± 0.07
Imperata cylindrica	0.03 ± 0.02	0.03 ± 0.02	0.00 ± 0.00	0.00 ± 0.00
Paspalum conjugatum	0.13 ± 0.08	0.09 ± 0.06	0.03 ± 0.02	0.05 ± 0.03
Digitaria ciliaris	0.01 ± 0.01	0.00 ± 0.00	0.00 ± 0.00	0.00 ± 0.00
Digitaria longiflora	0.00 ± 0.00	0.00 ± 0.00	0.01 ± 0.02	0.00 ± 0.00
All species	0.54 ± 0.17	0.50 ± 0.17	0.46 ± 0.08	0.38 ± 0.04

Note: Each value represents the transformed mean count (±SE) of six (2 × 2 m) quadrats per replicate, 3 replicates, and 6 seed banks obtained at 6-month intervals. Values are log (x + 1) transformed for analysis. Same letters after values in each row indicate significance at 0.05.

2000), and paraquat greatly reduces the germination of its seeds (Ahring and Stritzke, 1982). *E. indica* has the highest seedling emergence in both manual and chemical plots of 15% and 25% slope. However, *C. dactylon* was an exception in manual plots of 15% slope since it has equal counts with *E. indica*.

The high seedling emergence of *E. indica* could be due to the conditions in the greenhouse that favored germination. The greenhouse has an average day/night temperature of 33 / 28 °C and light intensity of 2.9 × 104 lux. Seeds of *E. indica* exhibit high germination when placed on soil surface and when exposed to high alternating temperatures like 30 / 20 °C and 35 / 25 °C (Chauhan and Johnson, 2008b). On the other hand, the high counts of *E. indica* in chemically treated plots can be attributed to the presence of paraquat-resistant individuals in the field that are able to set seeds even after herbicide application. The resistance of *E. indica* enabled it to build up its seed deposits in the soil.

In both slopes, *C. brevifolius*, *E. indica*, and *C. dactylon* were the most prevalent among the seven observed weed species. These have a great potential to build up a soil seed bank because the viability of their seeds are longer than the other species studied (Lunt, 1995).

C. brevifolius was observed to be the most persistent among the monocot weeds in 15%. However, this was inconsistent with field observations. This is because it exhibits high germination percentage only when exposed to high temperature and to open sunlight, which was not observed in the field (Lowe et al., 1999). The banana canopy in the field keeps the ground cool and shaded. The persistence of *C. brevifolius* could also be because it produces large quantities of seeds (Klinkhamer et al., 1987).

Field Counts and Biomass

In both 15% and 25% slope, the chemical plots have lower counts and biomass than manual plots, but the differences were generally not statistically significant (Tables 3 and 4). However, there were exceptions in the counts and biomass of *P. conjugatum* in 15% slope and *D. ciliaris* in 25% slope. Counts of *P. conjugatum* and biomass of *E. indica* were also significantly lesser in chemical plots of 25% slope.

P. conjugatum had significantly lesser counts in chemical plots of 15% and 25% slope and lesser biomass in 15% slope (Tables 3 and 4). This is because it can be effectively controlled by application of paraquat and glyphosate (Rao, 2000). Application of paraquat causes good initial desiccation and repeated sprays gave marked suppression on *P. conjugatum* (Headford, 2006). Treatment of glyphosate to *P. conjugatum* under shade results to greater injury and reduction (Sahid et al., 1996). In the 25% slope, *D. ciliaris* had significantly

Table 3. The effect of the two weed management treatments on the count and biomass of individual grass/sedge species in the 15% slope

Species	Count [√((N/4m²)+10)]		Biomass [√((g/4m²)+10)]	
	Manual	Chemical	Manual	Chemical
Cyperus brevifolius	3.21 ± 0.02	3.18 ± 0.01	3.19 ± 0.01	3.17 ± 0.01
Cynodon dactylon	4.05 ± 0.13	3.50 ± 0.08	3.48 ± 0.04	3.29 ± 0.02
Eleusine indica	3.32 ± 0.03	3.23 ± 0.02	3.30 ± 0.04	3.24 ± 0.02
Imperata cylindrica	3.18 ± 0.01	0.01 ± 0.00	3.20 ± 0.02	3.18 ± 0.01
Paspalum conjugatum	3.28 ± 0.04[a]	3.20 ± 0.02[a]	3.24 ± 0.03[b]	3.19 ± 0.01[b]
Digitaria ciliaris	3.16 ± 0.00	3.16 ± 0.00	3.16 ± 0.00	3.16 ± 0.00
Digitaria longiflora	3.17 ± 0.01	3.16 ± 0.00	3.17 ± 0.00	3.16 ± 0.00
All species	4.38 ± 0.11	3.62 ± 0.07	3.74 ± 0.07	3.40 ± 0.04

Note: Each value represents the transformed mean (±SE) of six (2 × 2 m) quadrats per replicate, 3 replicates, and 26 sampling months. Values are square root (x + 10) transformed for analysis. Same letters after values in each row indicate significance at 0.05.

Table 4. The effect of the two weed management treatments on the count and biomass of individual grass/sedge species in the 25% slope

Species	Count [√((N/4m²)+10)]		Biomass [√((g/4m²)+10)]	
	Manual	Chemical	Manual	Chemical
Cyperus brevifolius	3.29 ± 0.03	3.23 ± 0.02	3.22 ± 0.01	3.20 ± 0.01
Cynodon dactylon	7.04 ± 0.68	3.70 ± 0.10	5.40 ± 0.64	3.42 ± 0.06
Eleusine indica	3.37 ± 0.04	3.26 ± 0.02	3.50 ± 0.02[c]	3.26 ± 0.02[c]
Imperata cylindrica	3.18 ± 0.02	3.16 ± 0.00	3.16 ± 0.00	3.16 ± 0.00
Paspalum conjugatum	3.21 ± 0.04[a]	3.19 ± 0.02[a]	3.18 ± 0.01	3.17 ± 0.01
Digitaria ciliaris	3.18 ± 0.01[b]	3.16 ± 0.00[b]	3.17 ± 0.01[d]	3.16 ± 0.00[d]
Digitaria longiflora	3.19 ± 0.02	3.17 ± 0.00	3.17 ± 0.02	3.16 ± 0.00
All species	7.34 ± 0.69	3.86 ± 0.11	5.76 ± 0.69	3.55 ± 0.08

Note: Each value represents the transformed mean (±SE) of six (2 × 2 m) quadrats per replicate, 3 replicates, and 26 sampling months. Values are square root (x + 10) transformed for analysis. Same letters after values in each row indicate significance at 0.05.

lesser counts and biomass in chemical plots. This could be because paraquat effectively suppresses the species.

The biomass of *E. indica* in 25% slope was significantly lower in chemical plots (Table 4). Though *E. indica* was reportedly resistant to glyphosate (Kaundun et al., 2008 and Ng et al., 2004) and paraquat (Buker et al., 2002), the lower biomass in chemical plots could be due to evolutionary trade-off associated with paraquat resistance.

In manual and chemical plots in both 15% and 25% slopes, *E. indica* was the secondmost abundant species (Tables 3 and 4). Like *C. dactylon*, it produces phenolic compounds and hydroxamic acids that have allelopathic effects (Sanchez-Moreiras et al., 2003). However, its compressed and erect habit (Galinato et al., 1999) makes it less competitive for space compared to the spreading growth of *C. dactylon*.

Counts and biomass of monocot weeds species in manual plots of 15% and 25% slopes decreased with exception to 15% monocot weed counts. The slight increase in monocot weed counts of manual plots in 15% slope could be due to the increase in counts during September 2008. During this month, there was an increase in frequency of manual weeding (Table 1). This increased the fragmentation of perennial weeds like *C. dactylon*, which can regenerate from fragmented rhizomes. As a result, this increased the counts of monocot weed species in manually treated plots of 15% slope. However, this was not observed in 25% slope because there were higher monocot weed counts in manual plots of 25% slope during the first year of sampling compared to 15% slope. The decreasing biomass of weeds in manual plots in 15% and 25% slope and monocot weed counts in 25% slope could be due to competition against broadleaf weed species.

The maintained low counts and biomass of monocot weed species could be due to the cumulative effect of competition against broadleaves as well as effectiveness of herbicides. Broadleaf weed species were more prevalent in the experimental plots. In some banana plantations, broadleaf weed species were also reported to be more prevalent than grasses (Isaac et al., 2009; Fongod et al., 2010). Broadleaf weed species are more competitive than monocot weed species because of the wider horizontal leaves that makes them more competitive for light (Aldrich and Kremer, 1997). In the first year of observation, monocot weed species had approximately higher counts than broadleaves in 25% slope and relatively equal in 15% slope. However, the monthly weed control application during the first year of the experiment prevented the monocot weed species from producing seed. The most dominant broadleaf weed species, *A. conyzoides*, can complete its life cycle in less than two months and may also flower even at four-leaf stage (Galinato, 1999). Its shorter life cycle enabled it to frequently replenish seeds in the soil. Thus, even when weed control was relaxed in the second and third years, the monocot weed species failed to catch up with *A. conyzoides* and other broadleaves.

Species Composition

C. dactylon was the most dominant grass species, followed by *E. indica*, in both the 15% and 25% slope as well as in both manual and chemical plots (Tables 4 and 5). In the 15% slope, *E. indica* was followed by P. conjugatum, while *C. brevifolius* ranked next to *E. indica* in the 25% slope.

The dominance of *C. dactylon* in both slopes is because of its ability to suppress the growth of other grass weed species if it is the first one to colonize the area (Holm et al., 1977). Its spreading habit through its rhizomes and stolons makes it an aggressive colonizer (Horowitz, 1973), and its residues pose a direct threat to neighboring plants (Friedman and Horowitz, 1971). It produces phenolic compounds and hydroxamic acids that has allelopathic effects (Sanchez-Moreiras et al., 2003), and exhibits different levels of allelopathy in its parts (Alam et al., 2001). In a study by Rezaei and Yarnia (2009), *C. dactylon* root extracts inhibited the germination and reduced the growth of plants like safflower (*Carthamus tinctorius* L.), soybeans (Verma and Rao, 2006) and wheat (Alam et al., 2001).

Species Diversity

In 15% slope, species diversity in chemical plots was significantly higher from the first to third year of sampling year. However, in 25% slope, diversity in chemical plots was not significant in the second year of sampling (Table 5). Furthermore, the diversity index in chemical plots of both slopes remained stable, while it decreased in manual plots in 15% slope and increased 25% slope throughout the three sampling years. The low diversity in manually treated plots could be due to the existence of dominant noxious grasses that inhibited

Table 5. Mean grass/sedge species diversity (H') based on field counts for manual and chemical plots during the 3-year sampling period

Sampling year/ slope	Manual	Chemical	*p*-value
1st sampling year			
15% slope	1.607 ± 0.002	1.609 ± 0.001	0.005
25% slope	1.834 ± 0.032	1.943 ± 0.001	0.007
2nd sampling year			
15% slope	1.601 ± 0.007	1.609 ± 0.000	0.009
25% slope	1.914 ± 0.016	1.944 ± 0.001	0.078
3rd sampling year			
15% slope	1.936 ± 0.004	1.942 ± 0.002	0.027
25% slope	1.915 ± 0.010	1.943 ± 0.010	0.028

Note: Values were log (x + 1) transformed for analysis. Each value represents the mean of six (2 × 2 m) quadrats per replicate and three replicates over a 3-year sampling period.

the emergence of other monocot weed species. The effectiveness of chemical herbicides in controlling these noxious species accounts for the high species diversity in chemical plots. Decrease in counts of the dominant weed species, *C. dactylon*, allowed the emergence and succession of new species such as *D. longiflora* and *D. ciliaris*.

Though there was no significant difference between the manual and chemical plots, the relatively higher diversity found in chemical plots could be due to lesser soil disturbances. In manual weeding, plants are uprooted and soil loosens, thereby making it prone to soil erosion. This was worsened by the increased rainfall and also proven by the increase in soil loss in the third year of observation. This can lead to soil erosion, bringing with it weed seeds with it and resulting to lesser weed emergence (Li et al., 2009). On the other hand, since the paraquat keeps the soil intact, it is able to retain the seeds and allow other less noxious species to emerge after effective control of the dominant weed species.

Weed Management Cost

Chemical weeding was less laborious than manual weeding. It only used 18.47% as much labor as that of manual weeding (Table 6). Chemical weeding required only one laborer to complete the task for one day while manual weeding needed two laborers for two days. Because manual weeding is inefficient in systemically controlling weeds with rhizomatous roots typical of monocots, weed regrowth in the manual plots frequently occurred. The

Table 6. Comparison of costs incurred under 2 weed management treatments over the 4-year sampling period

	Manual weeding	Chemical weeding	
		Paraquat	Glyphosate
Labor requirements (0.3 ha)			
No. of laborers	2	1	1
Labor cost per day (PhP)[1]	199.00	199.00	199.00
Days to task completion	2	1	1
Weed management cost			
Labor cost (PhP)	796.00	199.00	199.00
Chemical cost (PhP)[2]	-	132.48	172.80
No. of applications	23	13	4
Total (PhP)	18,308.00	4,309.24	1,484.00
Total	18,308.00	5,793.24	

Notes:
[1] Based on the AJMR Holding company daily wage rate
[2] Cost for 0.36 L of the herbicide applied for 6 chemical plots (0.3 ha^{-1})

systemic herbicide paraquat efficiently suppressed the growth of rhizomatous weeds, thus, requiring less frequent application. Over the 3-year sampling period, manual weeding was performed 24 times. Chemical weeding, on the other hand, was only performed 17 times. The three-month cycle of systematic application of chemical weed control, paraquat-paraquat-glyphosate, reduced the weed management cost by 65.35% compared to manual weeding.

Summary and Conclusion

Two identical experiments were conducted in two slope conditions (15% and 25%) to compare the long term effects of manual and chemical weed control using glyphosate and paraquat on the growth, abundance, and diversity of monocot weed species present in a banana plantation. The study also aimed to determine the changes in paraquat resistance and fitness of *E. indica* in response to repeated application of paraquat.

Weed seed bank was studied by monitoring weed seed germination from soil samples collected from the field at 6-month interval. Seven monocot weed species were identified: *C. dactylon*, *C. brevifolius*, *E. indica*, *I. cylindrica*, *P. conjugatum*, *D. ciliaris*, and *D. longiflora*. Generally, there was a decreasing trend in the seed bank counts in both manual and chemical plots of 15% and 25% slope. However, the differences between treatments were not significant. *E. indica* have the highest seed bank counts in both manual and chemical plots of 15% and 25% slope. *C. dactylon* has equal counts with *E. indica* in manual plots of 15% slope, but it was significantly reduced in chemical plots of 15% slope.

Counts and biomass of monocot weed species were obtained from the field plots. Chemical treatments reduced the general counts and biomass of monocot weeds, but this effect was generally not significant. Chemical treatments significantly reduced the counts of *P. conjugatum* in 15% slope and the biomass of *E. indica* in 25% slope in the field. Herbicide rotation during the first year of study prevented the build up of paraquat-resistant weeds and accounts for the reduction of *E. indica* inspite of its resistance to paraquat, as shown in subsequent experiments. *C. dactylon* was found to be the dominant species in the field because of its early establishment in the slopes, its spreading growth, and its allelopathic properties, which suppressed other species.

There was a significant increase in diversity in both treatments on two slopes, but chemical plots had a significantly higher diversity compared to the manual plots.

Although there were no significant differences in the field counts, seed bank counts, and biomass of grass species, the significantly higher species diversity and the reduced weed management cost in the chemical plots renders chemical weed management more advantageous than manual weed management.

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