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Weed Density and Diversity under Two Weed Management Practices in Sloping Lands of Banana Plantation in Davao City, Philippines

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Abstract

Weed management in the slope farms of a banana plantation poses a challenge because the banana canopy provides a condition that allows weeds to proliferate, protecting fragile soil from erosion. If left uncontrolled, it could impair banana production. Manual weed removal disrupts soil structure that not only stimulates dormant seed germination but also increases soil erosion. Seedbanks, counts, dry weights, and diversity indices of broad-leaved weeds under two weed management systems (manual weeding and chemical weed control using cyclical application of paraquat and glyphosate) in a banana plantation were examined at two slope conditions: 15° and 25° inclination. Seedbanks at the start and six months after treatments yielded nine broad-leaved species of which three were dominant: Ageratum conyzoides, Bidens pilosa, and Cleome rutidosperma. While species diversity and seedling count from seedbanks were not significantly affected by weed management systems, the reduction in growth and abundance of the dominant species was achieved in chemical plots. Over ten regular observations in 13 months, there were consistently and significantly lower counts and dry weights of weeds in chemical plots than in manual plots. In addition, the shifts in weed population – from that dominated by noxious species to that composed of less noxious species – were achieved in chemical plots, which could have implications on the environment and the banana production. Regular monthly weeding can, within one year, reduce weed population to a level that could potentially impact soil erosion. To stabilize soil in sloping lands, weeding can be based on a threshold weed cover.

Keywords*:* broad leaf, glyphosate, herbicide, paraquat

1. Introduction

In Southeast Asia, land management has made notable changes strongly related in particular to agricultural land use in sloping lands (Phan Ha *et al.*, 2012). Under this condition, weeds are important as vegetative cover to prevent soil erosion. In the tropics, weed management is a constant challenge and becomes increasingly difficult with the trend towards the use of the sloping lands for major crop production like the banana.

Banana is one of the main export products of the Philippines and the country is one of the largest banana exporters in the world (Javelosa, 2006). Mindanao, an island in the southern part of the Philippines, has large banana plantations. In fact, for many years, banana is considered lifeblood of Mindanao's economy (Digal, 2007).

Recent trends show that the sloping lands are increasingly used for banana production. In these lands, the lack of vegetative cover contributes to soil erosion in slopes. This problem can be mitigated by weeds that grow between rows of crops. However, if weeds are allowed to grow unhampered to provide vegetative cover, it reduces quality and yields of crops and can make field operations difficult. Therefore, weeds should be managed properly to meet production targets while conserving soil. In banana plantations, manual and mechanical weeding are traditionally employed, but alternatives need to be explored to cut on cost and improve soil conservation. One alternative is the use of herbicides which is a practical, effective, and economical means of reducing early weed competition and crop production losses (Ashiq *et al.*, 2007). Herbicides have increasingly become a key component of weed management programs in developing countries because it requires minimal labor and less disturbance to the soil (Baghestani *et al.*, 2008). However, the use of herbicides on commercial crops brings out concerns on erosion of biodiversity and apprehensions over the effects of long-term herbicide applications which may reduce weed diversity and increase the number of susceptible species (Robinson and Sutherland, 2002). This calls for the cautious use of herbicides in order to meet the needs of increasing crop productivity without sacrificing soil conservation.

Previous researches on weed management have focused on controlling weeds and weed population shifts in annual crops such as soybean, maize, and wheat (Robinson *et al.*, 1984; Ball and Miller, 1990; Kapusta and Krauz, 1993; Tuesca *et al.*, 2001). There is also a good understanding on the effect of glyphosate in managing weeds (Krauz *et al*., 1996; Lich et *al.*, 1997; Derksen *et al*., 1999; Wehtje and Walker, 1999). However, there is little information on the effect of glyphosate in combination with non-systemic herbicides like paraquat on weed species succession, density, and diversity in a perennial crop like the banana.

This study compares the effects of manual weeding techniques and the use of paraquat and glyphosate on abundance and diversity of three dominant weeds (*A. conyzoides*, *B. pilosa*, and *C. rutidosperma*) in a banana plantation based on (a) seed bank samples and (b) counts and dry weights of weeds collected regularly from the field.

2. Methodology

2.1 Time, Place and Experimental Setup

The study was conducted from January 2006 to January 2007 in the banana plantations of AJMR Holding Company located in Manuel Guianga (7° 06’ 29” N, 125° 24’ 48” E, 528.96 m elevation), Tugbok District, Davao City, Mindanao, Philippines (Figure 1).

Identical experiments were conducted in two slope conditions, 15% (15° inclination) and 25% (25° inclination) slopes. The first two replicates of the experiment in 15% slope were located in Caparoso farm (7°05’32” N, 125°22’47” E) with an elevation of 651-700 m asl. The third replicate was situated in Jimenez farm (7°06’19” N, 125°23’55” E), with an elevation of 601-650 m asl. The Caparoso farm was previously planted with corn, upland rice, tomatoes, bell pepper and non-Cavendish bananas. Jimenez farm was formerly planted with coconut, coffee, peanuts, upland rice and sweet potatoes. Planting of Cavendish banana in Caparoso and Jimenez farms started in 2000. All the replicates for the 25% slope were located in Bringas Farm (7°05’36” N, 125°24’55” E), with an elevation of 501-550 m asl. Before being planted with banana in 2003, Bringas farm was previously planted with cacao.

Details of topographic mapping reveal the contour plains of the treatment plots having undulating slopes of 15% and 25% (Figure 1). Data points were determined through a land survey with the aid of a Global Positioning System (GPS) device. Images in the figure were outputs of ArcView Version 13 software.

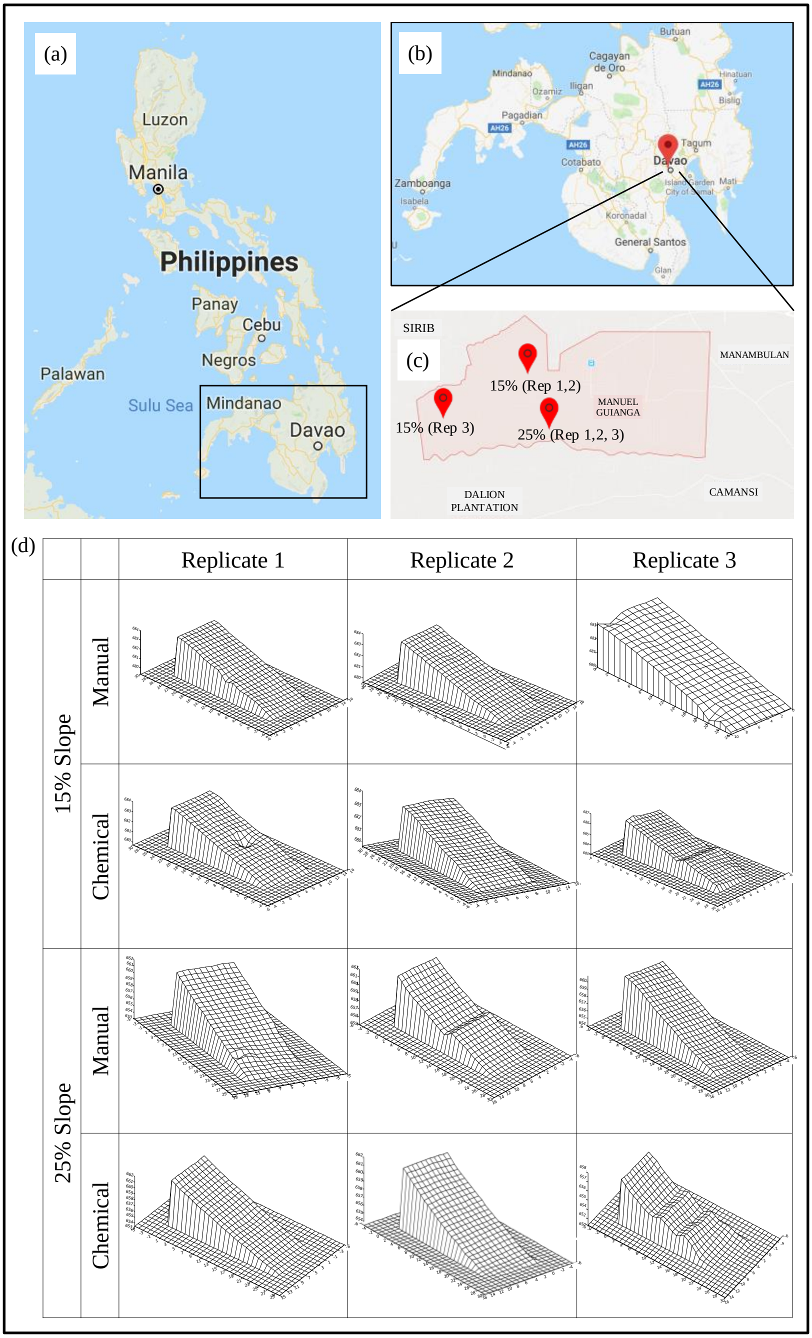

Figure 1. Location map of the sampling site in relation to the Philippines (a), Davao City in Mindanao (b), Manuel Guianga banana plantation (c) and topographic map of the contour plains of the treatment plots having undulating slopes of 15% and 25% (d). (Google Map, 2018)

The plots were laid out using a randomized complete block design (RCBD) with two treatments and three replications. Each treatment plot (manual and chemical) measured 10 m x 25 m (250 m^2) area. Each treatment plot was further divided into sixty 4 m^2 quadrats for weed sampling.

The experiment involved two treatments. Manual plots received monthly manual weeding while the chemical plots were treated with two applications of paraquat at monthly intervals followed by one-month glyphosate application. Manual weeding was done monthly and this involved three weeding techniques: manual slashing using a bolo around small plants; mechanized grass cutting in the main and secondary canals; and manual slashing and hand weeding inside the rows where the banana canopy closes.

Each application of paraquat (Gramoxone™) or glyphosate (Roundup™) had a formulated product rate of 5.5 L ha^{-1} and 2.25 L ha^{-1}, respectively. Initially, there were two paraquat applications at monthly intervals followed by one glyphosate application at the third month with each Gramoxone application containing 480 mL/ha active ingredient of paraquat and each Round-up™ application having 1680 mL/ha glyphosate. The herbicides were applied using a knapsack sprayer (in particular the lever-operated knapsack sprayer). The hollow cone nozzle type was used to achieve a fine drop size of <150 µm.

2.2 Seedbank

Soil samples were collected for seed bank count before the start of the experiment, and six months after the initiation of the treatments. The soil was sampled using a galvanized iron (GI) pipe with a diameter of 5 cm and a depth of 5 cm at ten random points following a Z-shape from six quadrats. The ten soil cores from each of the six quadrats were pooled to produce one sample per plot. Soil samples were taken at a depth of 5 cm because most seeds occur in the first 2 or 3 cm of soil, and numbers of seeds decline rapidly below this depth (Kim and Lee, 2005). Soil samples were stored in plastic bags prior to seed bank analysis.

Soil samples were spread thinly on top of a 2 cm layer steam-sterilized garden soil in plastic trays to initiate germination. The trays were placed in a rain shelter with a fine screen to prevent contamination from outside. The trays were checked for new seedlings every day for the first four weeks, and once a week thereafter for seven months. Upon counting and identification, seedlings were removed to promote the emergence of other seedlings. Unidentified seedlings were transplanted and grown to maturity for identification (Kim and Lee, 2005).

2.3 Weed Diversity Index

The measure of species diversity integrates the number of species (species richness) and the distribution of individuals among the species (species evenness). The data on counts for seedling emergence of broadleaf weeds from the two seedbank samples was used to calculate the Shannon-Weiner Index of Species Diversity (*H'*). The value for *H'* assumes that all species are represented in a sample and that the sample was obtained randomly (Molles 2002). This index accounts for abundance and rarity of species. It was calculated using Equation 1:

$$H' = - \Sigma P_i (\ln P_i) \tag{1}$$

where:

H' = the value of the Shannon-Wiener diversity index
P_i = the proportion of the ith species
$\ln P_i$ = the natural logarithm of P_i
s = the number of species in the community

The minimum value of *H'* is 0, which is the value of *H'* for a community with a single species (Molles, 2002). Both the number of species and their equitability, or evenness affects *H'*. The actual diversity value can be compared to the maximum possible diversity by using a measure called evenness. The evenness of the sample was obtained by dividing the Shannon-Wiener index (*H*') by ln *S*, where *S* is the total number of species.

2.4 Count and Dry Weights

Samples for counts and dry weights of weeds, sorted by species, were obtained from the same six quadrats where seed bank samples were collected. In exceptional cases when weed densities were very high (e.g., more than 1000 plants per quadrat), samples were obtained from half or a quarter of the quadrat selected at random (Heard *et al.*, 2003a). Samples were then oven-dried for 24 hours at 80 °C and weighed.

Sampling was made ten times (one to two weeks before the monthly weeding operation) over a 13-month period. In the beginning, three dominant weeds

(*A. conyzoides, B. pilosa*, and *C. rutidosperma*) were evaluated separately while the rest were evaluated collectively as other broad-leaved weeds. Later a fourth species (*Drymaria cordata*) which was previously not dominant, was recognized to be dominant and also evaluated separately.

2.5 Statistical Analysis

The data were analyzed using randomized complete design (RCBD) and the variant repeated measures analysis of variance (ANOVA) (Cropstat V7.0) by following the decision tree provided by Dubcovsky (2007). The data on counts and dry weights, and seed bank of weed species were log and square root transformed, respectively, prior to statistical analysis.

3. Results and Discussion

3.1 Seedbanks

At the start of the experiment, nine broad-leaved weed species were identified from both the manual and chemical plots in both 15% and 25% slopes: *A. conyzoides* L., *B. Pilosa* L., *C. rutidosperma* DC, and other broad-leaved weeds namely *Borreria laevis* (Lam.) Griseb, *Calopogonium muconoides* L., *Hedyotis corymbose* L., *Mimosa invisa* L., *D. cordata* L, and *Acalypha indica* L. The same set was observed six months after the initiation of weed control. Among the nine species, *A. conyzoides, B. pilosa*, and *C. rutidosperma* were the dominant species while other species present were almost equal in proportions. Consistently in both sampling dates and in both 15% and 25% slopes, there were no significant differences between the manual and chemical plots.

The apparent similarity between the two seed bank samples, in spite of six months of weed control, could be due to the short period between sampling times and the species-specific dormancy of some weeds which resulted in the spread of germination over time. This is consistent with Nakamoto *et al*. (2006), who failed to show a difference in seed bank composition of weeds under reduced tillage in wheat and maize cropping and partly attributed this observation to the experimental period that was too short to affect the density of buried seeds. Consistent with this explanation, *B. laevis, H. corymbosa*, and *C. muconoides* emerged on the third or fourth month while *M. invisa* emerged at the seventh month of observation. Galinato *et al*. (1999) noted that *M. invisa* seeds might remain dormant in the soil for years. In addition, seeds of shade-tolerant species like *M. invisa* do not often germinate immediately. The seeds germinate from seed banks persist for different periods of time, and represent different dormancy types (Zalamea *et al.*, 2018). A longer observation period may be needed to detect the impact of weed management on the seed bank.

3.2 Weed Diversity Index

The Shannon-Weiner Index (H^1) which is a measure of both species richness and species evenness shows that the chemical plots tend to have lower species diversity than the manual plots (Table 1). However, the difference was only significant in the initial seed bank of the 15% slope. Thus, it could not be attributed entirely to weed management treatment.

Table 1. Diversity indices of broad-leaved weeds in plots subjected to two weed management treatments[1]

Seedbank	15% Slope			25% Slope		
	Manual	Chemical	P-value[1]	Manual	Chemical	P-value
Initial	1.36 (0.62)	0.57 (0.26)	0.02	1.38 (0.92)	1.30 (0.76)	0.41
Six months after	2.02 (0.62)	1.68 (0.59)	0.86	1.21 (0.55)	1.15 (0.52)	0.84
P-value	0.96	0.04		0.13	0.16	

[1]Shannon-Weiner Index (J- Evenness)

Species diversity increased over time in the 15% slope but this increase was only significant in the chemical plot. In the 25% slope, both the chemical and manual plots did not show significant differences between initial and sixth-month sampling.

On the other hand, the increase in evenness could be due to the late emergence of other broad-leaved weeds towards the end of the seven-month observation period. The increase in species evenness in the chemical plot in a 15% slope suggests that chemical weed control reduced the dominance of specific broad-leaved weeds. This trend can be explained by the “sampling effect” concept (Tracy and Sanderson, 2003), which is caused by the increased probability that a diverse community would have at least one large, productive species that could use up the available resources in the local environment effectively (Wardle, 2001). The presence of a dominant species such as *A. conyzoides* could have suppressed the growth of other broad-leaved weeds in the absence of weed control. Upon initiation of weed control, however, the population of the dominant species could have been disproportionately reduced.

3.3 Counts and Dry Weights

3.3.1 Total for All Species

There was a significant fluctuation and a general tendency to decline in counts and dry weights of weeds in chemical plots and an increase in counts and dry weights in manual plots over the months for both 15% and 25% slopes (Figure 2).

In the 15% slope, in the months of May and October 2006, there were lower counts of weeds in manual plots than in chemical plots. However, the manual plots gave a higher dry weight than the chemical plots in May 2006. Apparently, weeds in the manual-treated plots were fewer but were bigger and heavier than the weeds in the herbicide-treated plots.

In 25% slope, in the months of March, August, and October 2006, the chemical plots yielded a higher number of counts and dry weights of weeds than the manual plots. However, these differences are not significant. The increase in counts in March 2006 could be due to the high rainfall (658.44 mm) recorded in the month preceding the sampling date.

Meanwhile, the exceptionally high weed count in October 2006 in chemical plots in both 15% and 25% slopes relative to the manual plots could be partly due to the unplanned change in manual weeding technique made in September 2006. Instead of the usual manual weeding, farmers switched to land scraping and cultivations. This modification in manual weeding techniques reduced the weed count for October in manual plots. However, the weed count in the manual plot recovered in December and January 2007. Land scraping and cultivation might have stirred the soil such that buried seeds were brought to the surface to germinate. On these consecutive months, the dry weights were also significantly higher in the manual plots than in chemical plots.

Another reason for the exceptionally high weed count in the chemical plots in October 2006 could be the effect of dry weather in the month preceding the last herbicide application. Ferrell *et al.* (2006) explained that during dry or hot weather, plants conserve water through changes in both the composition and thickness of the cuticle on the leaf surface. When plants develop thicker cuticles, the absorption, retention, and translocation of applied herbicides are reduced. This explains the apparent inefficiency of chemical weed control as shown by the high weed count in the chemical plot in October 2006.

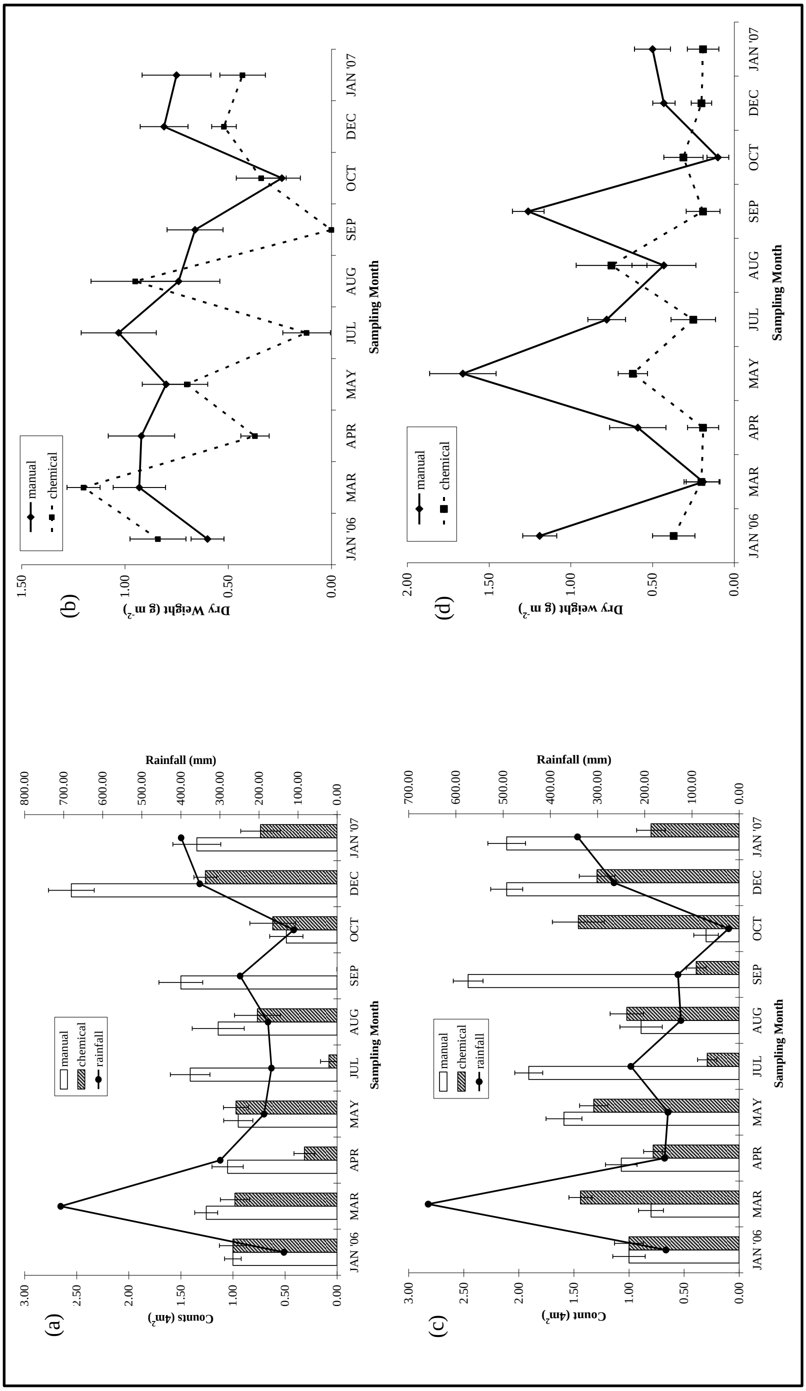

Figure 2. Effect of weed control on the count of total broadleaf weed species measured over time in 15% (a, b) and 25% (c, d) slope. Values are log transformed means with corresponding standard error bars. Pearson correlation: manual and rainfall r(8)=0.103, p-value=0.778; chemical and rainfall r(8)=-0.090, p-value=0.804.

3.3.2 Counts and Dry Weights by Species

Except for *C. rutidosperma*, counts and dry weights for *A. conyzoides*, *B. pilosa* and other broad-leaved weeds were significantly lower in chemical plots than in manual plots in 15% slope (Table 2). The significantly higher count and dry weight of *C. rutidosperma* in chemical plots could be due to the physiological characteristics of *C. rutidosperma* being the smallest plant with the smallest leaf area among the three dominant broad-leaved species. Since both paraquat and glyphosate herbicides act mainly through contact with foliage, larger plants with greater leaf area like *A. conyzoides* and *B. pilosa* are more likely to come into contact with the herbicide, while smaller weeds like *C. rutidosperma* can be sheltered by the larger weeds. This result is consistent with Heard *et al.* (2003b) for contrasting effects of herbicide on monocotyledons and dicotyledons.

Table 2. Effect of two weed management treatments on counts and dry weights of broad-leaved weeds in 15% and 25% slope. Values are log transformed for analysis.

Weed Species	15% Slope			25% Slope		
	Manual	Chemical	P-value	Manual	Chemical	P-value
Count (no/m^2)						
A. conyzoides	18.50±9.00	1.00±1.20	0.00	11.20±4.80	7.50±4.50	0.00
B. pilosa	3.00 ±1.00	2.50±0.70	0.04	1.20±0.60	0.30±0.10	0.00
C. rutidospema	0.80±0.40	1.80±1.80	0.03	3.70±1.40	2.90±2.10	0.00
Other broad-leaved weeds	33.90±17.30	2.70±4.20	0.00	3.30±0.80	2.50±1.10	0.00
Total	56.20	8.00		19.40	13.20	
LSD (0.05)	0.11				0.11	
Dry weight (g/m^2)						
A. conyzoides	5.40±1.72	4.40±2.51	0.03	4.30±1.64	3.40±2.07	0.00
B. pilosa	3.50±1.40	2.21±1.21	0.00	2.20±1.01	0.40±0.24	0.00
C. rutidospema	0.40±0.23	1.20±0.50	0.00	2.60±1.31	1.20±0.55	0.00
Other broad-leaved weeds	5.60±1.91	1.80±0.91	0.00	18.30±15.83	6.10±0.48	0.00
Total	14.90	9.61		27.40	11.10	
LSD (0.05)	0.08				0.93	

In the 15% slope, there was a slight shift in dominance among the weeds on three consecutive months from July to December 2006 (Figure 3). *B. pilosa* and *C. rutidosperma*, the dominant species decreased in counts and dry weights while other broad-leaved weeds increased. This is advantageous because the other broad-leaved weeds are less noxious compared to the dominant species (Rao, 2000).

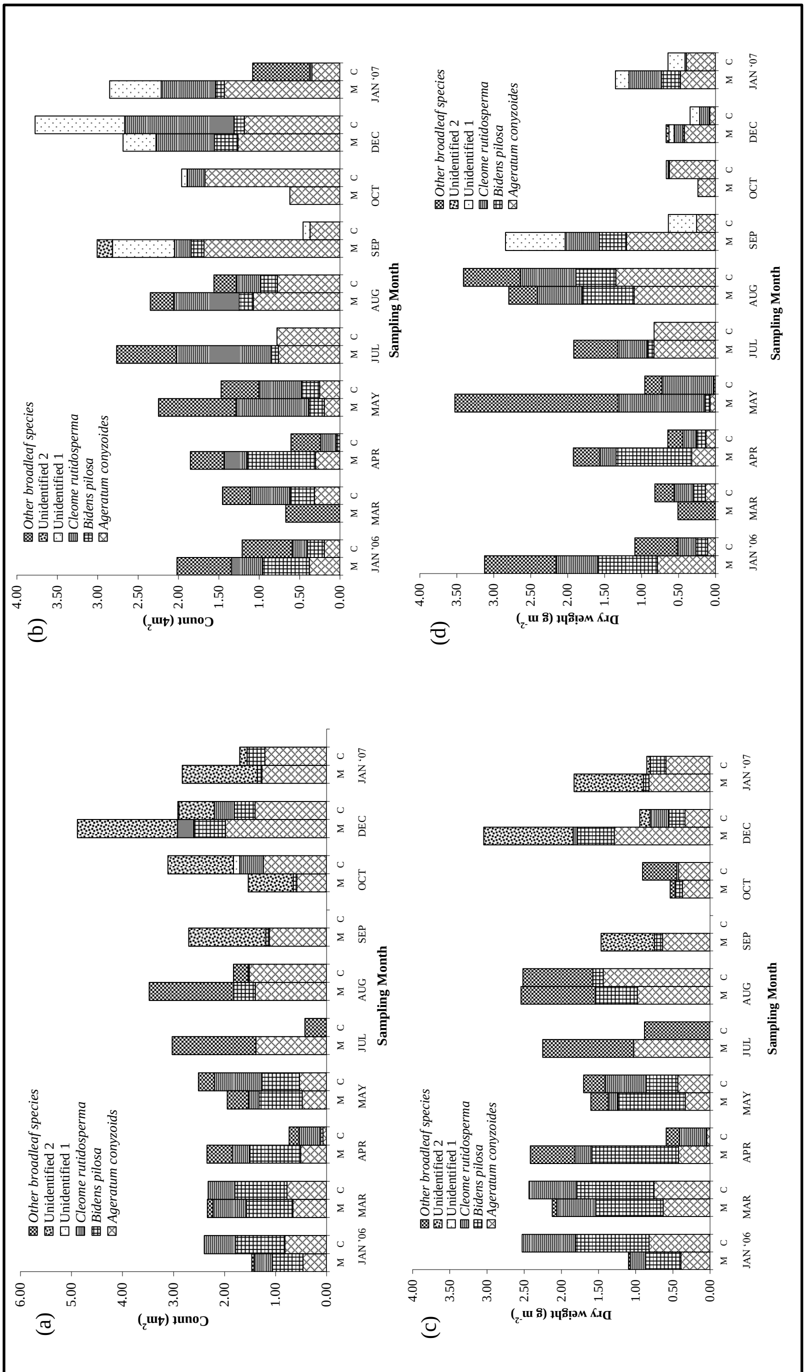

Figure 3. Effect of weed control method on the individual broadleaf weed species measured over time in 15% (a, c) and 25 % (b, d) slopes. M= manual weeding, C= chemical weed control

The dominance of *A. conyzoides* was maintained throughout the sampling period in both manual and chemical plots. *A. conyzoides* is an annual species that is able to flower in less than two months as two pairs of leaves are formed. Each plant could produce 40,000 seeds, half of which are viable to germinate (Galinato *et al*., 1999). Moreover, the hairy leaves and stalks of *A. conyzoides* species prevent the penetration of herbicides as these remain suspended on the hairs of the plant (Ferrell *et al*., 2006).

In 25% slope, the most dominant broad-leaved species in descending order were *A. conyzoides*, *C. rutidosperma*, and *B. pilosa* (Table 2). In 15% slope, *B. pilosa* was dominant over *C. rutidosperma*. This difference in dominance would seem likely due to the stronger taproot system and shorter plant height of *C. rutidosperma* compared to the towering height (1.5 m) of *B. pilosa*. In steep slopes, plants with stronger roots and shorter stature were more successful than those that had a weaker root system and taller stature (Chacko and Reddy, 1981). It could also be due to the higher amount of total rainfall in 15% slope (2784.06 mm) than in 25% slope (2233.26 mm) since *B. pilosa* species is favored by wet soil (Galinato *et al*., 1999).

In the first three months, *B. pilosa* was the most dominant broad-leaved species but its counts decreased throughout the sampling period. The opposite effect was observed *for A. conyzoides*, which increased in counts in the last months of the sampling period. The growth and abundance of *A. indica* were distinct and observed from September to December 2006.

These observations suggest that the dominant species changed depending on species throughout the sampling period. *B. pilosa* species was an early colonizer but its dominance declined in the course of the experiment. Seed production and seed germination of *B. pilosa* species are favored by continuous light and moisture availability (Galinato *et al.*, 1999). Since there was a dry period in the months of August to October 2006 in the 25% slope seed production of *B. pilosa* was likely inhibited and the few seeds produced may have failed to germinate.

In addition, the competition exerted by the increasing number of other broad-leaved weeds such as *A. indica* and D. *cordata* likely hindered the growth and abundance of *B. pilosa*. In the case of the increasing counts of *A. conyzoides*, it could be attributed to the species high adaptability exhibiting short reproductive cycle (less than two months), quick flowering and massive seed production (40,000 seeds plant^{-1}) (Galinato *et al.*, 1999).

4. Conclusion and Recommendation

In conclusion, the study showed that the chemical weed control using a combination of paraquat and glyphosate is more effective than manual control. This method reduced the growth and abundance of weeds especially the three dominant weed species *A. conyzoides*, *B. pilosa*, and *C. rutidosperma* while diversity of index of broad-leaved weeds was not affected. In the 15% slope *D. cordata* and *B. pilosa* became more abundant with time. In the 25% slope, the total other broad-leaved weeds increased in abundance and during some periods, matched that of *A. conyzoides*. In future studies, it is recommended that the growth and yield of banana must be evaluated. In addition, experiments on herbicide susceptibility and resistance may be necessary to provide insights in the continuous herbicide application in sloping lands of a banana plantation.

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