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Management of Mixed Weeds in Young Oil-palm Plantation with Selected Broad-Spectrum Herbicides

Rosli B. Mohamad[1*], Wahyu Wibawa[1], Mohd Ghazali Mohayidin[2], Adam B. Puteh[1], Abdul Shukor Juraimi[1], Yahya Awang[1] and Mohammad B. Mohd Lassim[1]

[1]*Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia*

[2]*Faculty of Business and Management, Open University Malaysia, 50480 Kuala Lumpur, Malaysia*

[*]*E-mail: rosli@agri.upm.edu.my*

ABSTRACT

A field study to evaluate the efficacy of three broad spectrum herbicides on mixed weed in a young (2 year-old) oil palm plantation was conducted. Experimental plots, with the size of 4.8 x 20.5 m^2 each, were laid in a randomized complete block design with 4 replications. Weed vegetation analysis was conducted before herbicide treatments were applied. Herbicide treatments used were paraquat and glufosinate-ammonium (200, 400, 600, 800 g a.i. ha^{-1}), and glyphosate (400, 800, 1200, 1600 g a.i. ha^{-1}), with untreated control. The experimental locality indicated a composite of mixed weeds of broadleaf and grasses. The growth of broadleaf was more dominant with 25 species (relative dominance of 82.1%) than the grasses with only 7 species (relative dominance of 17%). The three most dominant species were the broadleaves of *Croton hirtus* and *Asystasia gigantica*, and a grass, *Paspalum commersonii*. The percentage of the mixed weed composite killed was found to be significantly affected by the treatments of paraquat, glufosinate–ammonium and glyphosate, relative to the untreated control, with more than 50 percent weed killed taken at 2 and 4 WAT. Meanwhile, glyphosate and glufosinate-ammonium produced greater efficacy (more than 90 percent killed) as compared to paraquat which produced lower total weed killed (50 to 83%). There were positive correlations between the percentages of weed killed and weed growth reduction. Increased percentage of weed killed was followed by the increase in the percentage of weed growth reduction, with the indication that weeds were recovering and began to produce new shoots at 16 WAT. Treatments producing fewer efficacies caused weeds to regrow and recover faster or in a shorter time. Increased rates of paraquat treatments, i.e. from 200 to 600 and 800 g a.i. ha^{-1}, were found to increase the duration of effective weed control. The duration of effective weed control produced by glufosinate-ammonium at 200 to 800 g a.i. ha^{-1} and glyphosate at 400 to 1600 g a.i. ha^{-1} ranged from 14.5 to 15 weeks, which were significantly longer than the paraquat treatments. The increased rates of glufosinate-ammonium and glyphosate did not necessarily increase the duration of effective control.

Keywords: Mixed weeds, young oil-palm plantation, broad spectrum herbicides

INTRODUCTION

Weed is a major component in oil palm production system. The composition of weeds is a mixture of grasses, sedges, and broadleaves which often changes according to the crop growth stages which provide specific climatic and environmental conditions suitable for specific weed growth. The shade provided by the palm canopy influences the nature of weed composition, and grass species tend to dominate as the oil palms get bigger (Wan Mohamed *et al*., 1987). The effect of weeds on oil palm

[*]Corresponding Author

is difficult to quantify because of their long economic life (i.e. 20-30 years) but they can affect the growth of crops or cause yield losses (Kuan *et al.*, 1991).

Weeds in plantation are managed using several methods such as cultural, mechanical, integrated production system of using livestock to control the weeds, or chemical (herbicides). Weed management with the use of chemical herbicides is the most common practice in oil palm plantations at some stages of crop development. Broad spectrum herbicide, paraquat, was used for more than 40 years, and was the only mostly used herbicide in Malaysian plantations. The use of this herbicide, however, has been halted since 2002 by the Government of Malaysia, for reasons of toxicity and hazards to humans, but was lifted in 2006 to allow for more comprehensive study. The prohibition of paraquat use left an open option to users for replacement. Several other common broad-spectrum herbicides are available in the Malaysian market. Among these herbicides are glufosinate-ammonium and glyphosate. All these herbicides are foliar applied, with paraquat activity being through contact (Turner and Gilbanks, 2003), glufosinate-ammonium being partially systemic (Collins, 1991), and glyphosate being systemic (Chang and Liao, 2002).

Most herbicide efficacy studies in oil palm plantation have reported on certain specific noxious weeds (Chung and Balasubramanian, 1991; Pin and Lang, 1991; Ikuenobe and Ayeni, 1998; Utulu, 1998). Meanwhile, a study evaluating some new herbicides for general weed control in young oil palm was reported by Khairudin and Teoh (1990). However, a single predominant weed is rarely found under field condition. Instead, predominant weeds comprised of a few weed species (or rather it is a mixed weed situation) (Aldrich, 1984), and weed population, particularly in crop areas, are never constant, but are in dynamic state of flux due to changes in climatic and environmental conditions, husbandry methods, and the use of herbicides (Cobb, 1992). This study was undertaken to gather more current information on the control of natural mixed weeds in immature oil palm, whereby the use of broad spectrum herbicides is the most appropriate. It evaluates the efficacy and duration of effectiveness in using the broad spectrum herbicides of paraquat, glufosinate-ammonium and glyphosate on the total mixed weed population found in a young (2 year-old) oil palm plantation.

MATERIALS AND METHODS

Field Experimental Set-up and Initial Vegetation Analysis

The experiment was conducted in a two-year old oil-palm plantation at MAB Agriculture-Horticulture Sdn. Bhd. in Sepang, Selangor, Malaysia. The plots in the size of 4.8 x 20.5 m^2 each were set up in a randomized complete block experimental design with four replications.

An initial weed vegetation analysis was conducted in the experimental plots prior to the application of the herbicide treatments. It was conducted to determine the composition of weeds based on their species, density of growth, and species dominance in the experimental locality. The identification of the weed species was done according to Bernes and Lus (1990) and Sahid and Chan (2000). Meanwhile, the square method (0.5 x 0.5 m2) was used to sample and classify the weed species. Weeds were counted in 10 quadrates to determine their species, as well as to obtain the density and dominance of each species expressed in relative terms, using the following formulae (Derksen et al., 1993):

$$\text{Relative (X) of a species} = \frac{\text{Absolute (X) of the species}}{\text{Total absolute (X) of all species}} \times 100\%$$

where, X = density or dominance

Above ground weed vegetation was harvested and separated by species (for identification), sun-dried for 4 days and then oven-dried at 75^{0}C for 48 h (for dominance evaluation) (Felix and Owen, 1999).

Herbicide Treatments

The plots were sprayed in the manner of controlling weeds (at 200 L ha^{-1}), with four rates of each: paraquat (200, 400, 600, and 800 g a.i. ha^{-1}), glufosinate-ammonium (200, 400, 600, and 800 g a.i. ha^{-1}), and glyphosate (400, 800, 1200, and 1600 g a.i. ha^{-1}), and untreated control plots. The rates cover the range of the recommended rates for the field applications, namely paraquat (400-600g a.i. ha^{-1}), glufosinate-ammonium (500g a.i. ha^{-1}), and glyphosate (1000g a.i. ha^{-1}). The herbicide formulations used were Gramoxone^R (200g paraquat $liter^{-1}$, Syngenta Crop Protection), Basta 15^R (150g glufosinate-ammonium $liter^{-1}$, Bayer Cropscience), and Roundup^R (360g glyphosate $liter^{-1}$, Monsanto). The spraying was done manually using a knapsack sprayer fitted with AN 2.5 deflector nozzle.

Evaluation of Treatment Efficacy

The square method was also used to evaluate the degree of weeds controlled (killed, growth reduction, and duration) by the herbicide treatments. The samples were randomly taken at three locations in each experimental unit. Destructive and non-destructive samplings were used for this purpose. The percentages of the total weed killed and the total weed growth reduction relative to the untreated control plot, and the duration of effective control were evaluated. The percentage of weeds killed was taken at 2 and 4 weeks after the treatment (WAT) by counting the plants with all the tissues from the growing point to the soil surface being completely dead. The percentage of weed growth reduction was calculated from the dry weight of the weeds sampled at 8, 12, and 16 weeks after the treatments using the following formula (Pritchard, 2002; Chuah *et al*., 2004):

$$\%\ \text{growth reduction} = 100 - \frac{\text{Dry weight of samples from treated plot}}{\text{Dry weight of samples from untreated plots}} \times 100$$

Duration of effective weed control (i.e. a period when a treatment is able to suppress weed growth >50% relative to untreated plot) was deduced from the percentage of weed growth reduction. The data were obtained for 8, 12, and 16 WAT. The data between the narrowest observations, i.e. from 8 to 12 and 12 to 16 weeks after the treatments, were predicted using the regression analysis to estimate the correlations between the percentage weed killed to weed growth reduction, and the duration of effective weed control.

RESULTS AND DISCUSSION

Initial Weed Vegetation Analysis

Initial weed vegetation analysis is needed to determine the weed species present, and their density and dominance of growth at the locality of the experiment. Krueger *et al*. (2000) noticed that one of the keys for a successful post-emergent weed management strategy is the knowledge of weeds present in the field, and the density of each species. In fact, a single predominant weed is rarely found under field condition, and yet predominant weed is composed of few weed species (Aldrich, 1984). Weed populations, especially in crop areas, are never constant, but they are in dynamic state of flux due to the changes in climatic and environmental conditions and husbandry methods (Cobb, 1992). In the present study, the weed vegetation analysis recorded 32 weed species, indicating a composition of mixed weed species in the experimental area (Table 1). The composition is dominated by broadleaf species with 25 species (including remnants of cover crop species such as *Calopogonium* sp. and *Centrosema* sp.), and only 7 grass species.

The dominance of broadleaf species covering the area is obvious with their total relative density of 82.9% and relative dominance of 82.4% (Table 1). About 80% of the composition is represented by 10 species in term of their relative density and dominance. Among these, eight species were represented by the broadleaf, with only 2 species of grasses. Meanwhile, three

TABLE 1
Weed species composition of the experimental locality

Weed species	Type*	Relative density (%)	Relative dominance (%)
Ageratum conyzoides	B	6.6	3.4
Asystasia gangetica	B	11.4	12.9
Hedyotis verticillata	B	5.0	5.2
Borreria latifolia	B	3.8	7.5
Borreris repens	B	2.4	1.0
Cardiospermum halicacabum	B	0.39	0.1
Calopogoniun mucunoides	B	1.2	3.6
Centrosema pubescen	B	7.8	9.3
Cleome rutidosperma	B	2.5	3.1
Clidemia hirta	B	0.2	0.7
Croton hirtus	B	33.6	23.6
Emilia sonchifolia	B	1.6	0.8
Melastoma malabathricum	B	0.1	0.4
Cassia tora	B	0.2	0.3
Melochia corchorifolia	B	0.2	0.9
Mimosa invisa	B	0.2	0.2
Mimosa pigra	B	0.1	0.1
Mimosa pudica	B	1.0	1.9
Mikania micrantha	B	1.3	2.1
Oxalis barrelieri	B	1.4	1.1
Passiflora foetida	B	0.2	0.2
Phyllanthus amurus	B	1.2	2.4
Porophyllum ruderale	B	0.3	0.1
Rubus moluccanus	B	0.1	0.6
Synedrela nodiflora	B	0.1	0.9
Axonopus compressus	G	0.2	0.1
Paspalum commersonii	G	12.4	9.7
Brachiaria miliformis	G	0.2	0.1
Digitaria ciliaris	G	1.5	0.7
Eleusine indica	G	0.7	1.2
Ischaemum timorense	G	0.3	0.2
Pennisetum polystachyon	G	2.6	5.9

*B: broadleaf; G: grass

species were found to dominate the locality based on their relative density and dominance. These are two broadleaves of *Croton hirtus* and *Asystasia gigentica*, and one species of grass, *Paspalum commersonii*. The dominance of *Croton hirtus* was obvious with the relative density (33.6%) and dominance (23.6%) being much higher than the other species present, followed by the values for *Asystasia gigentica* (11.4% and 12.9%), and *Paspalum commersonii* (12.3% and 9.7%). Two species could be rated as being the least dominant. These were *Mimosa pigra* (broadleaf) with 0.1% and 0.1%, and *Bracharia miliformis* (grass) with 0.2% and 0.1%, respectively. Therefore, the experimental locality indicated a composite of mixed weeds of broadleaves and grasses, with the broadleaves being more dominant over the grasses. In this study, these are the weed species which were found to be growing with this state of relative density and dominance at this stage of oil palm growth and under the environmental condition in the plantation. The situation, therefore, necessitates the use of general post-emergent herbicides for chemical weed management in the locality of this experimentation.

Herbicide Efficacy

The efficacy of the treatments was evaluated as the effects on the total weed population (mixed weed situation of broadleaf and grasses). The percentage of the weeds killed was significantly affected by the treatments of paraquat (200 to 800g a.i. ha^{-1}), glufosinate –ammonium (200 to 800g a.i. ha^{-1}), and glyphosate (400 to 1600g a.i. ha^{-1}) relative to the untreated control, with at least more than 50% weed killed observed at 2 and 4 WAT. However, when the efficacy of these three herbicides was compared, paraquat was found to produce a lower weed killed (50 to 83%) in total than those by glufosinate-ammonium (between 91 to 98%), and glyphosate (between 95 to 100%) (*see* Table 2). Using the weed control rating proposed by Burill *et al.* (1976), i.e. where 70% killed was considered as the minimum acceptable level of control and more than 90% killed as an excellent level of control, paraquat at lower rates of 200 and 400 g a.i. ha^{-1} was considered to be less effective in killing the weeds in this mixed weed condition. At higher rates of 600 and 800 g a.i. ha^{-1}, paraquat was found to produce considerably good kill of the weeds (74 to 83%) over the 4 WAT period. These results, however, were lower than those produced by glufosinate-ammonium and glyphosate at all levels of treatments, which gave the kill of between 91 to 100% at the 4 WAT. Meanwhile, treatments at lower rates of each herbicide produced lower kill than those of the higher doses of the same chemical, except for glyphosate where only the lowest rate was significantly lower than the higher rates. Sampling times (i.e. at 2 and 4 WAT) did not indicate any differences in the percentage of weed killed for the herbicides at all the treatment rates. A significant difference in the weed killed was observed between the herbicides, with glyphosate giving the highest kill, and paraquat the lowest kill. Meanwhile, glyphosate and glufosinate-ammonium showed greater efficacy on this mixed weed population than paraquat. As mentioned earlier, the weed composition of the area suggested certain influence on the outcome of the treatments. The efficacy of these herbicides was affected by the nature of the weed composition of the area and the surrounding environment (especially light penetration) of the locality. The effect of paraquat is reduced in high light intensity because the leaves are damaged, particularly at the site of application (Ipor and Price, 1991). Herbicide treatments, in general, are affected by dominance of weed species, crop cultivated and environment, whereby they can be effectively controlled for several months (Hoerlein, 1994). Paraquat is a non-selective (broad-spectrum) and contact herbicide which has a tendency to injure broadleaf plants somewhat more than grasses at a given rate (Ashton and Crafts, 1981; Calderbank and Slade, 1975). Its greatest efficacy is on weed species with restricted root system or which are still small (Turner and Gillbanks, 2003), and inversely proportionate to moisture where its effect increases under moisture stress (Turner and Gillbanks, 2003). Glufosinate-ammonium

TABLE 2
The percentage of weed killed after the treatments with paraquat, glufosinate-ammonium and glyphosate to mixed weed composition

Treatment (g a.i. ha^{-1})	Mean percent weed killed*	
	2 weeks after treatment	4 weeks after treatment
Untreated	0 f	0 g
Paraquat 200	50.7 e	50.9 f
Paraquat 400	65.8 d	66.4 e
Paraquat 600	74.1 cd	74.1 e
Paraquat 800	81.6 c	82.6 d
Glufosinate amm. 200	82.0 c	91.6 c
Glufosinate amm. 400	83.6 c	95.1 bc
Glufosinate amm. 600	95.0 b	97.9 b
Glufosinate amm. 800	91.2 b	98.0 b
Glyphosate 400	83.1 c	95.8 b
Glyphosate 800	98.5 a	100 a
Glyphosate 1200	98.8 a	99.7 a
Glyphosate 1600	100 a	100 a
Standard error	0.65	0.60

*Means within the same column, followed by the same letter, are not significantly different at P<0.05 by DMRT

is a broad-spectrum (Maschoff *et al*., 2000) and partially systemic that tends to give more persistent control of grasses than paraquat (Collins, 1991), apart from the effect on the broadleaf weeds. Glyphosate, however, is a non-selective systemic herbicide. When applied to the foliage, it is absorbed by the leaves and readily translocated to other parts of the plant, making it very effective to even the perennial weeds (Collins, 1991). A complete translocation of this herbicide confers remarkably with the efficacy on most weeds, broadleaves, grasses, or sedges (Kataoka *et al*., 1996).

The weed dry weight influenced the reduction of weed growth, which reflected the relative capability of a treatment to suppress weed growth relative to the untreated control. The dry weight of weeds measured the productivity of the weed community. The dry weight of weeds recorded for all the treatments with paraquat, glufosinate-ammonium, and glyphosate was significantly ($p<0.05$) lower relative to the untreated check (Table 2). However, this degree of significance was observed until 12 WAT for the paraquat treatments, after which there was a sign of weed growth recovery. The recovery for paraquat treatments is faster because the herbicide fails to make contact with some parts of the plant, especially the enclosed growing point or shoot, making immediate regrowth of the weeds possible. Paraquat, which is widely used for broadleaf control, is a quick acting, non-selective compound that destroys green plant tissue; nonetheless, it has been reported to possibly temporarily suppress some annual grasses only because the low and enclosed growing points are not contacted by the spray (Collins, 1991). Ipor and Price (1991) reported that the effect of paraquat is reduced in high light intensity because the leaves are damaged, particularly at the site of application. Light intensity is high in the inter-rows of young oil palm plantation. Glufosinate-ammonium and glyphosate treatments, however, are more lasting with low weed dry weight recorded until 16 WAT (45.3 and 45.9 g, respectively) as compared to the untreated check at 76.2g. The glufosinate-ammonium and glyphosate treatments, therefore, have higher ability to reduce the weed population dry weight than paraquat. In particular, glufosinate-ammonium is more persistent in controlling grasses than paraquat (Collins, 1991), and the treatment rates are affected by the dominance of the weed species, crop cultivated and environment, whereby they can be effectively controlled for several months (Hoerlein, 1994). As for glyphosate, the treated plants were found to die in 1-3 weeks (Chang and Liao, 2002), while the development of symptom was also shown to be slow but irreversible (Collins, 1991). Shift in weed composition is a consequence of differential effectiveness of herbicides (Wrucke and Arnold, 1985; Swanton *et al.*, 1993).

Based on the dry weight, weed growth reduction was observed to be significantly affected ($p<0.05$) by paraquat, glufosinate-ammonium and glyphosate treatments at 8, 12, and 16 WAT relative to the untreated control. The glufosinate-ammonium and glyphosate treatments recorded similar results within each sampling time, which ranged between 73 to 82% and 69 to 71%, respectively, for the 8 and 12 WAT (*see* Table 3). However, the paraquat treatment recorded lower growth reductions of 27 to 65% and 38 to 55%, respectively. The results also showed the tendency of weed growth recovery for all the treatments from the 8 to 12 to 16 WAT. The growth of weeds was increased by 25 to 40% over these sampling periods for all the treatments. There were positive correlations between the percentages of weed killed and reduction of weed growth. The increase in the percentage of weed killed was followed by the increase in the percentage of weed growth reduction, as indicated by the regressions $y = 0.0022x^2 + 0.4752x + 1.7461$, $y = 0.0014x^2 + 0.6446X + 1.5315$, $y = 0.0027x^2 + 0.1464x + 0.7233$, and R^2 values of 0.81, 0.87 and 0.66 at 8, 12 and 16 WAT, respectively (see *Fig. 1*). The degree of correlation was stronger for the 8 and 12 WAT, showing that the weeds were still dying until 12 WAT. Meanwhile, the correlation at 16 WAT was lower, and this indicated that the weeds were recovering and began to produce shoots even though the initial weed killed was 70%. These findings prove that the treatments of less efficacy could cause weed to grow and

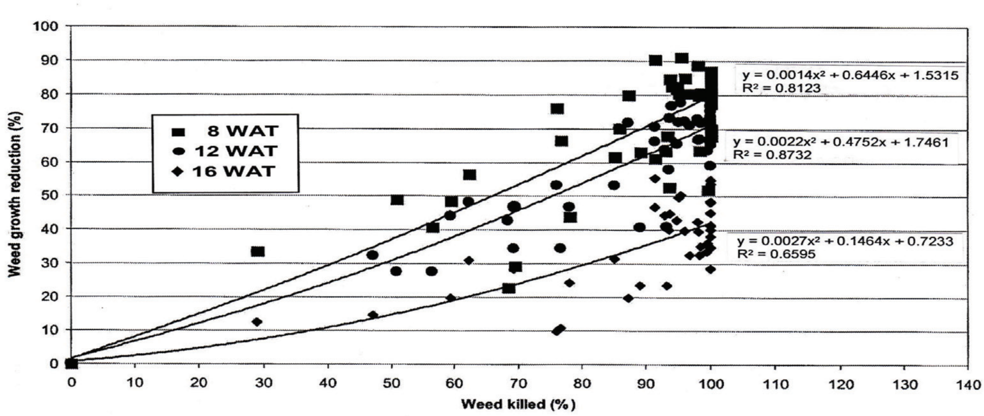

Fig. 1:Relationship between weed growth reduction and weed killed

TABLE 3
Weed dry weight and growth reduction after treatments with paraquat, glufosinate-ammonium and glyphosate

Treatment (g a.i. ha^{-1})	Dry weight (g/0.25m^2)*			Growth reduction (%)*		
	8WAT	12WAT	16WAT	8WAT	12WAT	16WAT
Untreated	60.9 a	73.2 a	76.2 a	0e	0d	0c
Paraquat 200	42.6 ab	44.7 b	66.5 a	26.9 d	38.2 c	12.4 b
Paraquat 400	33.7 bc	44.4 b	67.9 a	39.7 cd	38.8 c	11.5 b
Paraquat 600	28.0 bc	39.9 bc	62.7 a	53.3 bc	44.5	17.5 b
Paraquat 800	21.4 cd	32.4 c	60.9 a	64.5 ab	54.6 b	20.2 b
Glufosinate-amm. 200	12.9 e	22.1 d	42.0 b	76.5 a	69.3 a	45.6 a
Glufosinate-amm. 400	11.9 e	20.7 d	44.5 b	80.0 a	71.2 a	41.8 a
Glufosinate-amm. 600	12.5 e	20.5 d	44.5 b	78.1 a	71.3 a	41.5 a
Glufosinate-amm. 800	14.8 de	21.6 d	45.3 b	73.2 a	70.2 a	40.5 a
Glyphosate 400	13.5 e	22.3 d	45.5 b	76.9 a	69.6 a	40.5 a
Glyphosate 800	11.0 e	21.0 d	45.9 b	81.5 a	72.8 a	39.6a
Glyphosate 1200	11.7 e	21.7 d	42.0 b	79.7 a	69.8 a	44.8 a
Glyphosate 1600	12.4 e	21.2 d	44.7 b	78.1 a	71.3 a	41.3 a
Standard error	0.02	0.00	0.01	1.02	0.51	1.02

*Means within the same column followed by the same letter are not significantly different at $P<0.05$ by DMRT

recover faster or in shorter times. Chung and Balasubramaniam (1991) reported that the high biomass recorded after the treatment with certain herbicides was caused by a rapid regeneration of the weeds.

The percentage weed killed, weed dry weight, and percentage of weed growth, as components of efficacy evaluation, also reflects the duration of effective weed control. The higher percentage of weed killed lead to longer duration of effective control as indicated by the value of regression $y = 0.0013x^2 + 0.0215x + 0.219$, and R^2 of 0.84 (see *Fig. 2*). When weed killed was at 70% (i.e. the minimum acceptable control according to Burill *et al.*, 1976), the control only lasted for 8 weeks, as compared to more than 12 weeks when it was at 90% weed killed. The paraquat treatments had a duration of effective weed control that ranged from 4 to 11.75 weeks. The increased rates of paraquat treatment, i.e. from 200 to 600 and 800g a.i. ha^{-1} were found to increase the duration of effective weed control (*see* Table 4). The effective weed control produced by glufosinate-ammonium (at 200 to 800g a.i. ha^{-1}) and glyphosate (at 400 to 1600g a.i. ha^{-1}) ranged from 14.5 to 15 weeks, and these were significantly longer than the paraquat treatments. The increased rates of

TABLE 4
Duration of effective control after treatment with paraquat, glufosinate-ammonium and glyphosate on mixed weed in young oil palm plantation

Treatment (g a.i. ha^{-1})	Duration of weed control (week)*
Untreated	0 e
Paraquat 200	4.00 d
Paraquat 400	6.00 d
Paraquat 600	8.75 c
Paraquat 800	11.75 b
Glufosinate-ammonium 200	15.00 a
Glufosinate-ammonium 400	14.75 a
Glufosinate-ammonium 600	14.75 a
Glufosinate-ammonium 800	14.75 a
Glyphosate 400	14.50 a
Glyphosate 800	14.75 a
Glyphosate 1200	14.75 a
Glyphosate 1600	14.75 a
Standard error	0.24

*Means within the same column followed by the same letter are not significantly different at P<0.05 by DMRT

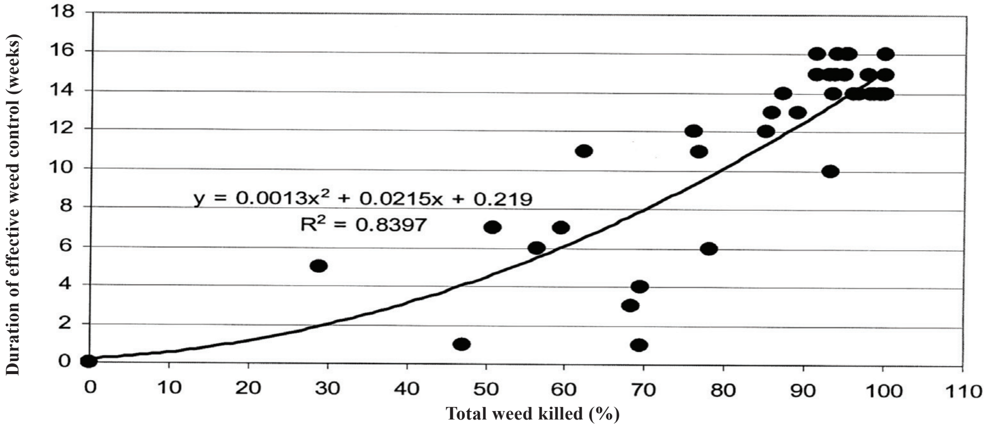

Fig. 2: Relationship between duration of effective weed control and weed killed

glufosinate-ammonium and glyphosate were not necessarily followed by their ability to increase the duration of effective weed control. This indicated that the percentage of weed killed plays an important role in evaluating the efficacy of herbicides applied because it affects the percentage of weed growth reduction and duration of effective weed control.

CONCLUSIONS

Weeds present in young oil palm plantation are of the mixed species of broadleawves and grasses. Broadleaves grow with greater density and dominance than grasses. In this study, treatments of the weeds using broad-spectrum, contact herbicides of paraquat, or partially systemic glufosinate-ammonium, or systemic glyphosate at around their recommended field application rates were found to provide effective kill, growth reduction, and duration of control in the mixed weed population. However, glufosinate-ammonium and glyphosate were found to be more effective than paraquat. Similarly, increasing the rates (200 to 800 g a.i. ha^{-1}) increased the efficacy for paraquat, but increasing the rates for glufosinate-ammonium (200 to 800 g a.i. ha^{-1}) and glyphosate (400 to 1600 g a.i. ha^{-1}) produced the same effect. Herbicide treatments with poor efficacy caused weeds to grow and recover faster or within shorter periods. The higher percentage of weed killed leads to longer duration of effective weed control.

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