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RESEARCH ARTICLE

THE EFFECTIVENESS OF THREE HERBICIDES MIXED WITH METSULFURON METHYL IN CONTROLLING WEEDS ON TWO TYPES OF SOIL IN SMALLHOLDERS OIL PALM PLANTATION

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ABSTRACT

Field experiment was conducted on six-year oil palm plantation in Central Bengkulu Regency in 2012 to evaluate the efficacy and cost effectiveness of three herbicides mixed with metsulfuron-methyl in controlling weeds on mineral and peat soil. The experiment was laid out in Randomized Complete Blocks Design (RCBD) with three replications. Seven herbicide treatments consisted of control (check), paraquat at 600 g active ingredient (a.i) ha^{-1}, glyphosate at 600 a.i. ha^{-1}, oxyfluorfen at 600 g a.i. ha^{-1}, paraquat at 600 g a.i. + metsulfuron-methyl at 75 g a.i. ha^{-1}, glyphosate at 600 g a.i + metsulfuron-methyl at 75 g a.i. ha^{-1}, and oxyfluorfen at 600 g a.i. + metsulfuron-methyl at 75 g a.i ha^{-1}. The results showed that: (1). Composition and weed species on peat soil were more complex and various than on mineral soil. (2). Paraquat and oxyfluorfen on single application were not effective to control weed on peat soil, meanwhile glyphosate was effective to control weeds on both mineral and peat soil. (3). The duration of effective weed control on mineral soil (9 -12 weeks) was longer than on peat soil (6-8 weeks) on various herbicide treatments. (4). Glyphosate on single application had the most cost effectiveness in controling weeds on both mineral and peat soil. (5). Glyphosate is sugested to be used in mature oil palm provided by its efficacy, cost effectiveness and safety for human and environment. Proper choice and use of herbicide has broad impact not only on the growers but also on human health and environmental safety.

INTRODUCTION

Weed management is recognized as an essential component of oil palm plantation because crop yield is affected markedly by presence of weeds (Alloub *et al*., 2000). The effect of weeds on oil palm is dificult to quantify because of their long economic life (20-30 year) but they can affect the growth crops or cause yield losses (Rosli *et al*., 2010). In general, cost to control weeds in oil palm is the second highest after fertilizer cost (Sahid and Chan, 2000). Weeds in oil palm plantation are managed using several methods such as cultural, mechanical or chemical. Using herbicide to control weeds is the most common practice in Indonesian oil palm plantation. Herbicides applied for weed control at recommended field application rates did not cause adverse effect on oil-palm crop development and production (Wahyu *et al*., 2007). Blanked spray is the most common applied by smallholders oil palm plantation. Mechanical and planting cover crop are rarely applied by growers for controlling weeds. Growers are very ussual in using herbicides, but their knowledge needs to be increased. In general, growers' knowledge about dominance of weed species, toxicity, handling and choosing herbicides is still low, meanwhile numbers of herbicide formulation registered by Indonesian Government are not less than 662 formulations (Directory of Fertilizers and Pesticides, 2011). Herbicides are not problem-free, but there are many reasons why they are such a popular form of weed control (Esterninos and Moody, 1988). Herbicides offer the most practical, effective, and economical means of managing weeds problem, thereby reducing crop losses and lowering production cost (Wahyu *et al*., 2010a). Each herbicide has specific characteristics to control weeds due to its spesific mode of action. The efficacy of herbicide in controlling weeds is important, but its adverse effects for environmental safety and human health should also be considered.

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Preferred herbicides should not only have good efficacy, but also pose minimum adverse effects to crop, ecology and environment (Faheed and Abd-Elfattah, 2007). Paraquat and glyphosate are the most commonly used herbicides in oil palm plantation (Chung and Sharma, 1999). Paraquat and glyphosate are grouped as broad spectrum herbicides (Directory of Fertilizers and Pesticides, 2011). Oxyluorfen is a selective contact herbicide used to control annual broad-leaved weeds and grasses, by pre- or post-emergence application. Metsulfuron-methyl is selective, systemic with contact and residual action. It inhibits plant amino acid synthesis. It is absorbed through the roots and foliage and translocated to the apex of the plants. Symptoms appear within days with death within 2-4 weeks. Metsulfuron-methyl is added to increase the efficacy of mix herbicides. Most growers perceive that paraquat is the most cost effectiveness and provides the fastest mode of action to control weeds. In general, the growers do not understand mode of action of each herbicide applied, so that they often use improper dose and tend to over dose in using herbicides. Term of mode of action, injury, and weed killed should be understood well to avert improper perception. Sometimes, the growers were confused in using injury and weed killed terms. So far, most applicators and growers perceived efficacy based on period required by herbicide to show injury on weed controlled (Wahyu *et al*., 2010b). Efficacy is the ability of pesticides to produce a desired effect on a target organism. Efficacy can be measured by several ways namely percentage of weed killed, percentage of weed growth reduction and duration of effective weed control (Pritchard, 2002). The efficacy alone is not enough to determine suitable herbicides in weed management. Cost-effectiveness of herbicides applied is also needed to support in making decision. Chung and Lam (1991); Turner and Gillbanks (2003) calculated weed control cost ha^{-1} $year^{-1}$ with summed 3 or 4 cost components, namely, herbicide cost, labour cost, number of spray $round^{-1}$ $year^{-1}$ and water transport.

Most herbicide efficacy studies in oil palm plantation have reported on certain spesific noxious weeds (Rosli *et al*., 2010). However, a single predominant weed is rarely found under field condition. Instead, predominant weeds comprised of a few weeds species (mixed weed situation). Nowadays and in the future, oil palm in Indonesia is not only cultivated on mineral soil but also on peat soil. This study was undertaken to gather more current information on the control of natural mixed weeds in mature oil palm cultivated on mineral and peat soil. The treatments having good efficacy do not always become the most cost-effective, because they are affected by many factors. The aim of the present study was to evaluate the efficacy and cost effectiveness of three herbicides mixed with metsulfuron-methyl in controlling weeds on mineral and peat soil.

MATERIALS AND METHODS

Field Experimental set-up and Initial Weed Vegetation Analysis

Six year old oil-palms planted on mineral and peat soil were used in this experiment. The experiment was conducted on smallholders oil palm plantation. The plots in size 8 x 27 m each were set up in a Randomized Completely Block Design (RCBD) with three replications (Gomez and Gomez, 1984). Each plot consisted of 3 oil palm crops with 9.1 x 9.1 m planting space. An initial vegetation analysis was conducted in the experimental area prior to the application of the herbicides treatments. It was conducted to determine the composition of weeds based on their species, density of growth, and species dominance in the experimental location. The square method (0.50 x 0.50 m) was used to sample and classify the weed species (Burrill *et al*., 1976). Above ground weed vegetation was harvested and separated by species (for identification), sun dried for 4 days and then oven dried at 75°C (for dominance evaluation) (Felix and Owen, 1999). The predominance of a species and homogeneity of weed community were expressed as Important Value Index (IVI) or Summed Dominance Ratio (SDR). IVI or SDR values show how important and dominant of a weed species in composing weed community. The higher value of IVI or SDR indicate the more important of species in the community. SDR value is more prefered than IVI value because its total value is never more than 100%. The CC value indicate homogeneity of weed communities devided into 5 classes, namely, excellent (91-100%), good (71-90%), fair (56-70%), poor (45-55%) and unacceptable (<45%) (Bonham, 1989). The major or dominant weed species were determined by computing SDR values (Sukarwo, 1991) as follows:

$$\text{SDR of a species} = \frac{\text{relative density} + \text{relative frequency} + \text{relative dominance}}{3}$$

Community coefficient was computed as suggested by Bonham (1989) and Sukarwo (1991).

$$CC = \sum w \ (\%)$$

Where, w = lower SDR value of each species from communities compared

Herbicide treatments

There were 7 herbicide treatments applied, namely, (1). control (check), (2). Paraquat at 600 g a.i ha^{-1}, (3). Glyphosate at 600 g a.i. ha^{-1}, (4). Oxyfluorfen at 600 g a.i. ha^{-1}, (5) Paraquat at 600 g a.i. + metsulfuron- methil at 75 g a.i. ha^{-1}, (6). Glyphosate at 600 g a.i + metsulfuron-methyl at 75 g a.i. ha^{-1}, and (7). Oxyfluorfen at 600 g a.i. + metsulfuron-methyl at 75 g a.i ha^{-1}. Knapsack sprayer fitted with deflector nozzle was used to deliver 300 l ha^{-1} of herbicide solution. Blanket spray was applied in this experiment.

Evaluation of Efficacy

The square method was used to evaluate weed control caused by herbicide application. Percentage of weed killed was calculated as described in Alloub *et al*. (2000) and Pritchard (2002). Weeds killed meant that all tissue from growing point to soil surface were completely dead. Evaluation of weed dry weight at 8 and 12 weeks after treatment (WAT) was done as described in Felix and Owen (1999), and the percentage of weed growth reduction was calculated as described in Lanie *et al*. (1993); Lanie *et al*. (1994); Murray *et al*. (1994); Pritchard (2002); and Chuah *et al*. (2004). The formula of percentage of growth reduction is as follow:

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

In which:

0 percent of growth reduction = no weed control
10 percent of growth reduction = very poor weed control
20 percent of growth reduction = poor weed control
30 percent of growth reduction = poor to deficient weed control
40 percent of growth reduction = deficient weed control
50 percent of growth reduction = deficient to moderate weed control
60 percent of growth reduction = moderate weed control
70 percent of growth reduction = weed control somewhat less than satisfactory
80 percent of growth reduction = satisfactory to good weed control
90 percent of growth reduction = very good to excellent weed control
100 percent of growth reduction = complete weed destruction

The duration of effective weed control is the period where a treatment was able to suppress weed growth, in term of weed dry weight, ≥50 percent relative to untreated. This characteristic was calculated based on percentage of weed growth reduction values at 8, and 12 WAT. Number of actual spraying round year^{-1} refers to the re-spraying needed to get satisfactory weed control. Unit of the duration of effective weed control was week and there are 52 weeks year^{-1} (Wahyu *et al*., 2010a).

$$\text{Spraying round year}^{-1} = \frac{\text{52 weeks}}{\text{Duration of effective weed control (week)}}$$

Cost-effectiveness

The major operational costs to control weeds were herbicide cost, labor cost and actual number of spray round year^{-1}. Weed control cost ha^{-1} year^{-1} (Wahyu *et al*., 2010a) can be formulated as follow: Cost ha^{-1} year^{-1} = [(herbicide price l^{-1} x herbicide dose l^{-1} ha) + labour cost + water cost] x number of actual spraying round year^{-1} Based on survey data, labour cost in Central Bengkulu was US$ 7.73 ha^{-1} and workers capacity were 1 ha^{-1} man^{-1} day^{-1}. Water transportation cost sometimes was not computed as cost component because water supply was available in the field like pond, stream, or drain water. Price of herbicides was based on the price recorded in August 2012.

RESULT AND DISCUSSION

Initial Weed Vegetation Analysis

Result of these studies showed that grass weeds were more dominant than broadleaf weeds in both peat and mineral soil. Weed dominance shows important value of a weed species in composting weed composition. On peat soil, 83.93% of weed composition was represented by 15 weed species, namely *Paspalum disticum* (SDR : 22.04), *P. commersonii* (SDR : 19.41), *Ipomea triloba* (SDR : 8.85), *P. longifolium* (SDR : 5.32), Bacopa procumbens (SDR: 5.29), *Panicum repens* (SDR: 4.22), *Hidrolea spinosa* (SDR: 3.94), *Brachiaria repan* (SDR: 3.77), *P. conjugatum* (SDR:2.62), *Ischaemum rugosum* (SDR:1.59), *Eleocharis congerta* (SDR:1.54), *Melastoma affine* (SDR:1.53), *Fimbristilis miliaceae* (SDR: 1.49), *Blumea tenella* (SDR:1.35), and *Basilicum polystachyon* (SDR:0.98). There were 48 weeds species found with various densities and dominances. In general, grass weeds were much more dominant

(66.65%) than broadleaf weeds (33.35%) (Appendix 1). On mineral soil, 80.28% of weeds was represented by 10 spesies of weeds, namely *Ipomoa triloba* (SDR: 21.62), *Borreria leavis* (SDR: 4.93), *Melastoma affine* (SDR: 2.32), *Lindernia procumbens* (SDR: 2.18), *Croton hirtus* (SDR: 2.10), *Brachiaria reptans* (SDR: 23.23), *Paspalum commersonii* (SDR: 10.93), *Imperata cilindrica* (SDR: 7.50), *Axonopus compresus* (SDR: 2.77), *Paspalum conjugatum* (SDR : 2.70). There were 35 weeds species found with various densities and dominances. In general, grass weeds were more dominant (53.33%) than broadleaf weeds (46.67%) (Appendix 2). Grass weeds on peat soil were more dominant (66.65%) than grass weeds on mineral soil (53.33%). Dominant weed species on peat soil were *Paspalum disticum*, *P. commersonii*, *P. longifolium, P. repens* and *I. triloba,* meanwhile dominant weed species on mineral soil were *B. reptans*, *P. commersonii*, *I. cilindrica, I. triloba*, and *B. leavis*. The numbers of weed species found on peat soil were higher (48 species) than that on mineral soil (35 species).

The predominance of a species and homogeneity of weed community were expressed as IVI or SDR and CC. IVI or SDR values show how important and dominant of a weed species in composing weed community. The higher value of IVI or SDR indicates the more important of species in the community. SDR value is more preferred than IVI value because its total value is never more than 100%. On the same age and planting space, the growth and development of oil-palm crop on mineral soil were better than those on peat soil. Optimum growth of oil palm crop was followed by increasing size of canopy and degree of shading. The higher degree of shading cause the lower sun light penetration. This fact influenced density, frequency, dominance of weed species. The composition of weeds is a mixture of grassess, sedges, and broadleaves which often changes according to the crop growth stages which provide specific climatic and environmental conditions suitable for spesific weed growth. The shade provided by the palm canopy influences the nature of weed composition (Rosli *et al*., 2010). Initial weed vegetation analysis is needed to determine the weed species present, and their density and dominance of growth at the location 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 weed 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. Weed populations, especially in crop areas are never constant caused by changes in climatic and environmental conditions and husbandry methods (Wahyu *et al*., 2009). Coefficient community is an indicator to know level of weed homogeneity on areas used to conduct experimental weed control. Coefficient community of mixed weeds on mineral and peat soil were 71.47 – 74.31% and 71.08 – 71.73% respectively. This condition was clasified as good homogenities to conduct weed control experiment (Bonham, 1989).

Herbicide Efficacy

Percentage of weed killed on peat soil

The percentage of weeds killed was significantly influenced by the herbicides treatments. Percentage of grass weed killed on 2, 4, and 6 WAT ranged from 7.70% - 46.57%, 32.60% - 82.57%, and 47.25% - 83.81% respectively. Percentage of broadleaf weed killed on 2, 4, and 6 WAT ranged from 2.07% - 65.25%, 33.23% - 91.10%, and 48.75% - 91.90% respectively. Percentage of total weed killed (broadleaf + grass) on 2, 4, and 6 WAT ranged from 9.34% - 34.76%, 33.39% - 71.88%, and 47.25% - 83.81% respectively (Table 1). Table 1 showed that paraquat and oxyfluorfen on single application were not effective to control weed on peat soil, meanwhile glyphosate on single or combination with metsulfuron-methyl was effective to control weeds on peat soil. However, when the efficacy of these three herbicides was compared, paraquat and Oxyfluorfen were found to produce a lower weed killed in total (65.55% and 51.61%) than those by glyphosate (73.68%). In general, herbicides had better ability to control broadleaf weeds than grass weeds. 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 location. The effect of paraquat is reduced in high light intensity because the leaves are damaged, particulary at the site of application (Rosli *et al*., 2010). Paraquat and oxyfluorfen are broad-spectrum which have a tendency to injure broadleaf plants somewhat more than grasses. Some annual grasses may only be temporarily suppressed, because the low and enclosed growing points are not contacted by the spray. Their greatest efficacy is on weed species with restricted root system or which are still small (Turner and Gillbank, 2003). Glyphosate is a systemic herbicide and it is much more effective againts weeds with well-developed root system or underground storage organs. Low application rate of 370 g ha^{-1} has sometimes been used to remove grass and broadleaf weeds without adverse effects for immature oil palm as long as it was not sprayed directly to the plant (Turner and Gillbank, 2003).

Percentage of weed killed on mineral soil

Percentage of weed killed is one of a good indicator to evaluate efficacy of herbicides applied. The percentage of weeds killed was significantly affected by the herbicides treatments. On 2 and 4 WAT percentage of grass weed killed were 18.00% - 67.66% and 52.26% - 100% respectively. On 2 WAT there was no treatment that able to control weed effectively (Table 2). On 2 and 4 WAT percentage of total weed killed (grasses + broadleaves) were 26.66% - 55.92% dan 64.36% - 98.67% respectively. 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. Treatments that able to control weed effectively were paraquat at 600 g a.i. ha^{-1}, glyphosate at 600 g a.i. ha^{-1}, paraquat at 600 g a.i. + metsulfuron-methyl at 75 g a.i. ha^{-1},

Table 1. Percentage of weed killed by paraquat, glyphosate and oxyfluorfen on smallholders oil palm cultivated on peat soil

Treatments	Percentage of weed killed (%) [a]								
	2 WAT			4 WAT			6 WAT		
	roadleaf	grasses	B. leaf + Grasses	Broadleaf	grasses	B. leaf + Grasses	Broadleaf	grasses	B. leaf + Grasses
Control (Check)	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0.00 a	0,00 a	0,00 a	0,00 a
Paraquat at 600 g a.i. ha^{-1}	26,63 a	7,70 a	33,07 b	33,23 b	55,00 b	52,75 b	48,75 b	65,56 b	65,55 b
Glyphosate at 600 g a.i. ha^{-1}	13,28 a	8,83 b	26,46 b	45,28 b	58,61 b	67,15 b	63,57 b	75,68 b	73,68 b
Oxyfluorfen at 600 g a.i. ha^{-1}	34,09 a	12,9 b	22,29 b	59,88 b	36,81 b	47,66 b	74,79 b	51,61 b	51,61 b
Paraquat at 600 g a.i. + Metsulfuron-methyl 75 g a.i. ha^{-1}	65,25 b	29,96 b	34,76 b	80,12 c	67,91 c	71,88 c	86,76 b	77,52 b	77,52 b
Glyphosate at 600 ga.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	12,05 a	28,85 b	31,39 b	65,69 b	82,57 c	68,17 b	85,95 b	83,81 c	83,81 c
Oxyfluorfen 600 g a.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	2,07 a	46,57 c	9,34 a	91,10 c	32,60 b	33,39 b	91,90 b	47,25 b	47,25 b

[a]Means within the same column, followed by the same letter are not significantly diferent at P<0.05 by LSD.

glyphosate at 600 g a.i. + metsulfuron-methyl at 75 g a.i. ha^{-1}, dan oxyfluorfen 600 a.i. ha^{-1} + metsulfuron-methyl at 75 g a.i. ha^{-1}. This result showed that the effectiveness of oxyfluorfen was lower than the others (paraquat and glyphosate). Ashton dan Crafts (1981) stated that oxyfluorfen is a contact herbicide that can be applied through soil (soil application) dan through parts of plant (foliar application). This herbicide is used to control annual weeds by pre-emergence and foliar application. This herbicide is not grouped in selective herbicide, but it has narrow spectrum compared with paraquat and glyphosate. Oil palm areas used to conduct experimental weed control were dominated by parennial weed as well as broadleaf or grass weeds (*I. triloba*, *B. leavis*, *M. affine*, *B. reptans*, *P. commersonii*, *I. cilindrica*, *A. compresus*, *P conjugatum*). Weed composition affected the efficacy of herbicides applied, so that oxyfluorfen was not effective to control mixed weeds dominated by parennial weeds. Paraquat is a non selective 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 Gilbanks, 2003), and inversely propotionate to moisture where its effect increases under moisture stress (Turner and Gillbanks, 2003). Glyphosete, however, is a non-selective systemic herbicide. When applied the foliage, it is absorbed by the leaves and readily translocated to other parts of plant, making it very effective even on the perennial weeds (Collins, 1991). A complete translocation of this herbicide confers remarkably with the efficcacy on most weeds, broadleaves, grasses and sedges (Kataoka *et al*., 1996). Based on this result, oxyfluorfen and paraquat herbicides were not recommended to be applied in peat soil areas having complex weed composition and species. Paraquat is still recommended on mineral soil areas, but oxyfluorfen is not recommended on both mineral and peat soil areas. In general, herbicides had better ability to control weeds on mineral soil than those on peat soil. This condition was affected by the environment, composition weed present, density and species of weed.

lower percentage of mixed weed growth reduction (38.86% - 44.81%) than other herbicides, paraquat (60.93% - 61.07%) and glyphosate (60.10% -60.85%). On peat soil areas oxyfluorfen herbicide had lower percentage of mixed weed growth reduction (23.11% - 30.45%) than other herbicides, paraquat (30.48% - 38.11%) and glyphosate (50.02% - 52.88%). This result proved that on 8 WAT, treatment with glyphosat had the highest ability to control weed in peat soil area compared with others. This condition was affected by the ability of herbicides to kill weeds. The efficacy of herbicides applied was affected by the nature of the weed composition of the area and the surrounding environment (especially light penetration) of the location. The effect of paraquat and oxyfluorfen is reduced by 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 (Hoerlin, 1994). Paraquat is a non selective 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 Gilbanks, 2003), and inversely propotionate to moisture where its effect increases under moisture stress (Turner and Gillbanks, 2003). Glyphosete, however, is a non-selective systemic herbicide. When it is applied on the foliage, it is absorbed by the leaves and readily translocated to other parts of plant, making it very effective, even on the perennial weeds (Collins,1991). A complete translocation of this herbicide confers remarkably with the efficcacy on most weeds, broadleaves, grasses and sedges (Kataoka *et al*., 1996). Based on this result, oxyfluorfen and paraquat herbicides were not recommended to be applied in peat soil areas having complex weed composition and species. Paraquat is still recommended on mineral soil areas, but oxyfluorfen is not recommended on both mineral and peat soil areas.

Table 2. Percentage of weed killed by paraquat, glyphosate and oxyfluorfen on smallholders oil palm cultivated on mineral soil.

Treatments	Percentage of weed killed (%) [a]					
	2 WAT			4 WAT		
	Broadleaf	grass	Total (grass+b.leaf)	Broadleaf	grass	Total (grass+b.leaf)
Control (Check)	0,00 a	0,00 a	0,00 a	0,00 a	0,00a	0,00 a
Paraquat at 600 g a.i. ha^{-1}	49,24 b	46,30 b	47,85 b	90,71 b	79,98 b	83,00 c
Glyphosate at 600 g a.i. ha^{-1}	58,15 b	42,05 b	50,72 b	100,00 c	97,21 b	98,67 d
Oxyfluorfen at 600 g a.i. ha^{-1}	34,45 a	33,30 b	34,36 b	82,45 b	52,60 b	64,36 b
Paraquat at 600 g a.i. + metsulfuron- methyl 75 g a.i. ha^{-1}	46,70 b	67,66 c	55,92 c	96,06 c	100,00c	94,75 c
Glyphosate at 600 ga.i. + metsulfuron- methyl 75 g a.i. ha^{-1}	71,15 c	46,87 b	55,64 c	96,85 c	89,17 b	89,00 c
Oxyfluorfen 600 g a.i. + metsulfuron- methyl 75 g a.i. ha^{-1}	34,05 b	18,00 b	26,66 b	65,15 b	75,05 b	75,45 b

[a]Means within the same column, followed by the same letter are not significantly diferent at $P<0.05$ by LSD.

Tabel 3. Percentage of weed growth reduction on 8 WAT on mineral and peat soil.

Treatments	Percentage of weed growth reduction [a]					
	8 WAT on mineral soil			8 WAT on peat soil		
	Broadleaf	grasses	B leaves + grasses	Broadleaf	grasses	B leaves + grasses
Control (Check)	0,00 a	0,00 a	0,00 a	0,00 a	0,00 a	0,00 a
Paraquat at 600 g a.i. ha^{-1}	75,40 c	55,11 b	61,07 c	54,21 b	24,21 a	30,48 b
Glyphosate at 600 g a.i. ha^{-1}	70,65 c	54,25 b	60,85 c	53,07 b	48,68 c	50,02 c
Oxyfluorfen at 600 g a.i. ha^{-1}	50,19 b	40,96 b	44,81 b	51,98 b	18,25 a	23,11 b
Paraquat at 600 g a.i. + metsulfuron methyl 75 g a.i. ha^{-1}	74,89 c	51,40 b	60,93 c	60,06 b	32,15 a	38,11 b
Glyphosate at 600 ga.i.+ metsulfuron methyl 75 g a.i. ha^{-1}	70,18 c	53,61 b	60,10 c	60,91 b	51,26 c	52,88 c
Oxyfluorfen 600 g a.i. + metsulfuron methyl 75 g a.i. ha^{-1}	44,84 b	33,96 b	38,86 b	53,51 b	24,38 a	30,45 b

[a]Means within the same column, followed by the same letter are not significantly diferent at $P<0.05$ LSD.

Percentage of weed growth reduction

Herbicide treatments affected mixed weed growth reduction on mineral and peat soil significantly (Table 3). The mixed weed growth reductions on mineral (38.86 – 61.07%) were higher than on peat soil (23.11 - 52.88%). On mineral soil areas oxyfluorfen herbicide had

In general, herbicides had ability to control weeds on mineral weed soil than on peat soil (Table 3). This condition was affected by the environment, composition weed present, density and species of weed. Weed growth reduction ilustrated the ability of treatments to control weed growth. Weed growth reduction reflected the capability of a particular treatment to suppres weed growth compared to the untreated check. The higher weed growth reduction values reflected the heigher ability of a treatment to reduce weed growth.

Duration of Effective Weed Control

Table 4 showed that different results can be happened on the same active ingredient and dose of herbicides applied in different areas or agroecosystems. For example, paraquat on single application had 6 weeks duration on peat soil and 12 weeks duration on mineral soil. Herbicide treatments, in general, are influenced by dominance of weed species, crop cultivated, and environment, whereby they can be effectively controlled for several months (Hoerlin, 1994). In general, paraquat and glyphosate herbicides had better efficacy and longer duration (12 weeks) of effective weed control than those of oxyfluorfen (9 weeks). Compared with paraquat, glyphosate had better efficacy and longer duration of effective weed control, especially on peat soil. Duration of effective weed control affected the frequency of spraying herbicide in a year. The longer duration of effective weed control the lower frequency of spraying herbicide per year. Duration of effective weed control is the best indicator to evaluate herbicide efficacy. This parameter is accumulative from efficacy components that consist of percentage of weed killed, weed dry weight, percentage of weed regrowth, and percentage of weed growth reduction. The better efficacy was showed by the higher percentage of weed killed and percentage of weed growth reduction. In general, longer duration of effective weed control is produced by treatment with high percentage weed killed, low weed dry weight, and high percentage of weed growth reduction. These findings prove that the treatments of less efficacy could cause weed to grow and recover faster or in shorter times. Rosli *et al*. (2010) reported that there were positive correlations between the percentage of weed killed and the increase in the percentage of weed growth reduction. Chung and Sharif (1991) reported that 50% of weed growth reduction is minimum level in re-spraying to achieve a good weed control. Utulu (1998) categoried that 50% of weed growth reduction grouped in moderate level of weed control. Duration of effective weed control calculated from formulae used by Utulu (1998) ranged from 6 to 12 weeks (Table 4).

Table 4. Duration of effective weed control affected by herbicides on mineral and peat soil

Perlakuan	Weeks	
	Peat soil	Mineral soil
Control (Check)	0	0
Paraquat at 600 g a.i. ha^{-1}	6	12
Glyphosate at 600 g a.i. ha^{-1}	8	12
Oxyfluorfen at 600 g a.i. ha^{-1}	6	9
Paraquat at 600 g a.i. + metsulfuron methyl 75 g a.i. ha^{-1}	7	12
Glyphosate at 600 ga.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	8	12
Oxyfluorfen 600 g a.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	6	9

Table 5. Weed control cost (US$ ha^{-1} $year^{-1}$)

Treatments	Frequency of spraying $year^{-1}$	Cost (US$ $year^{-1}$)
Mineral soil		
Control (Check)	0.00	0.00
Paraquat at 600 g a.i. ha^{-1}	4.33	107.13
Glyphosate at 600 g a.i. ha^{-1}	4.33	78.21
Oxyfluorfen at 600 g a.i. ha^{-1}	5.78	417.11
Paraquat at 600 g a.i. + metsulfuron- methyl 75 g a.i. ha^{-1}	4.33	140.61
Glyphosate at 600 ga.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	4.33	94.95
Oxyfluorfen 600 g a.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	5.78	439,46
Peat Soil		
Control (Check)	0.00	0.00
Paraquat at 600 g a.i. ha^{-1}	8.67	214.52
Glyphosate at 600 g a.i. ha^{-1}	6.50	117.40
Oxyfluorfen at 600 g a.i. ha^{-1}	8.67	625.67
Paraquat at 600 g a.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	7.43	248.03
Glyphosate at 600 ga.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	6.50	142.53
Oxyfluorfen 600 g a.i. + metsulfuron-methyl 75 g a.i. ha^{-1}	8.67	659.19

Weed Control Cost

Duration of effective weed control affected the frequency of spraying herbicide in a year. The longer duration of effective weed control the lower frequency of spraying herbicide per year. Cost needed for weed control is affected by the efficacy of herbicide, duration of effective weed control, labour, and price of herbicides. Glyphosate herbicides in singgle application were more cost effective (US$ 78.21 ha^{-1}) than paraquat and oxyfluorfen namely, US$107.13 ha^{-1} $year^{-1}$ and 417.11 ha^{-1} $year^{-1}$, respectively (Table 5). Mixing with metsulfuron-methil did not increase efficacy and efficiency in controling weed in mature oil palm, so that adding methil metsulfuron is not recommanded to control weed in mature oil palm on peat or mineral soils. In general, cost needed in controling weed in peat soil was higher than in mineral soil.

Conclusions

Composition and weed species on peat soil were more complex and various than those on mineral soil. Paraquat and Oxyfluorfen on single application were not effective to control weed on peat soil, meanwhile Glyphosate was effective to control weeds on both mineral and peat soil. The duration of effective weed control on mineral soil (9 -12 weeks) was longer than those on peat soil (6-8 weeks) on various herbicide treatments. Glyphosate on single application had the most cost effectiveness in controlling weeds on both mineral and peat soil. Glyphosate is sugested to be used in mature oil palm based on its efficacy, cost effectiveness and safety for human and environment. Proper choice and use of herbicide have broad impact not only on the growers but also on human health and environmental safety.

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Appendix 1: Weed species and dominance on peat soil

No	Spesies Gulma	SDR (%)
	Broadleaf	
1.	*Ageratum conyzoides*	0.00
2.	*Allmania nodiflora*	0.71
3.	*Athroiismala ciniatum*	0.29
4.	*Bacopa floribunda*	0.68
5.	*Bacopa procumbens*	5.29
6.	*Basilicum polystachyon*	3.94
7.	*Bidens pilosa*	0.60
8.	*Blumea tenella*	1.35
9.	*Boerchavia erecta*	0.62
10.	*Boreria alata*	0.75
11.	*Boreria laevis*	0.61
12.	*Borreria repens*	0.31
13.	*Celosia argentea*	0.31
14.	*Croton hirtus*	0.93
15.	*Emilia sonchifolia*	0.23

Continue…………

15.	*Emilia sonchifolia*	0.23
16.	*Heliotropium indicum*	0.24
17.	*Hydrolea spinosa*	0.98
18.	*Ipomea triloba*	8.85
19.	*Lindernia crustasea*	0.69
20.	*Melastoma affihe*	1.53
21.	*Melochia corchorifolia*	0.59
22.	*Mikania Micrantha*	0.80
23.	*Phyllanthus sp*	0.26
24.	*Pogostemon aurkutapia*	0.12
25.	*Retala rosea*	0.29
26.	*Rotala indica*	0.59
27.	*Neprolepis biserratas*	0.40
28.	*Stenochaena palustris*	0.37
29.	*Vernonia cinerea*	0.80
	Grasses	
30.	*Brachiaria reptans*	3.77
31.	*Cyperus brevifolius*	0.22
32.	*Cyperus cephalotes*	0.74
33.	*Cyperus halpan*	0.41
34.	*Cyperus pygmaeus*	0.70
35.	*Echinochloa crusgalli*	0.83
36.	*Eleocharis congesta*	1.54
37.	*Erioeaulon longifolium*	0.46
38.	*Erragratis tenella*	0.33
39.	*Frimbristylis miliaceae*	1.49
40.	*Frimbristylis ovata*	0.39
41.	*Fimbristylis tomentosa*	0.25
42.	*Imperata cylindrica*	0.57
43.	*Ischaemum rugosum*	1.59
44.	*Panicum repens*	4.22
45.	*Paspalum commersonii*	19.41
46.	*Paspalum conjugatum*	2.62
47.	*Paspalum distichum*	22.04
48.	*Paspalum longifolium*	5.32
Total		100.00

Appendix 2: Weed species and their dominance on mineral soil

No	Weed species	SDR (%)
1.	*Dicranopteris linnearis*	0.31
2.	*Nephrolepis biserrata*	0.30
3.	*Stenochlaena palustris*	0.53
4.	*Artanema longifolium*	0.56
5.	*Althernanthera sessilus*	0.34
6.	*Bacopa procumbens*	2.03
7.	*Borreria alata*	1.43
8.	*Borreria leavis*	4.93
9.	*Borreria repens*	0.35
10.	*Commelina sp*	0.32
11.	*Croton hirtus*	2.10
12.	*Hypenthus attenvalus*	1.11
13.	*Ipomoea triloba*	21.62
14.	*Lindernia crustesea*	2.03
15.	*Lindernia procumbens*	2.18
16.	*Melastoma affine*	2.32
17.	*Melochia corchorifolia*	0.60
18.	*Passiflora foetida*	0.41
19.	*Polygala paniculata*	0.76
20.	*Sphenoclea zeylanica*	0.69
21.	*Spigelia anthelmia*	0.37
22.	*Stachytarpeta indica*	0.27
23.	*Stachytarpheta jamaicencis*	1.10
24.	*Axonopus compressus*	2.77
25.	*Brachiaria mutica*	0.73
26.	*Brachiaria reptans*	23.23
27.	*Echinocloa colonum*	0.82
28.	*Fimbristylis tomentosa*	1.46
29.	*Imperata cylindrica*	7.50
30.	*Ischaemum rugosum*	0.47
31.	*Paspalum commersonii*	10.93
32.	*Paspalum conjugatum*	2.70
33.	*Paspalum distichum*	0.67
34.	*Paspalum longifolium*	1.62
35.	*Panicum repens*	0.43
Total		100