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Full Length Research Paper

Comparative impact of a single application of selected broad spectrum herbicides on ecological components of oil palm plantation

Wahyu Wibawa[1], Rosli B. Mohamad[1]*, Dzolkhifli Omar[2], Nurmasirah Mohd. Zain[1], Adam B. Puteh[1] and Yahya Awang[1]

[1]Department of Crop Science, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.
[2]Department of Plant Protection, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia.

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Proper choice and use of herbicides are important for the effective control of weed and environmental safety. Herbicides which possess both characteristics are preferred for use in weed control operation. A study was, therefore, conducted to compare the performance of common broad-spectrum herbicides of paraquat, glyphosate and glufosinate-ammonium to control weeds and their impact to the surrounding ecological components of an oil palm plantation. Field experiments set up in the oil palm plantation were sprayed accordingly with recommended rates of the herbicides (paraquat, 600 g a.i. ha^{-1}; glufosinate-ammonium, 600 g a.i. ha^{-1} and glyphosate, 1200 g a.i. ha^{-1}) at 200 L ha^{-1}, using knapsack sprayer fitted with a 2.5 deflector nozzle. Untreated control plots were included in the experiment. The effectiveness of the herbicides on weed population, their residues in the soil and indirect effects on oil palm crop plants were evaluated. Paraquat killed 74% of the weed population with effective control period of 8.8 WAT, whereas, both glyphosate and glufosinate-ammonium caused maximum killed of 99% and remained effective until 14.8 WAT. The measurements of weed dry weight and growth reduction also indicated that the herbicides caused significant reduction compared with the control, but paraquat was comparatively less effective than glyphosate and glufosinate-ammonium. Minimal and insignificant residue levels of the herbicides were detected in the soil after application which caused no significant detrimental effect on oil palm crop development and production, or the microorganism populations (fungi and bacteria) in the soil. The study indicated that the use of the herbicides can be effective in controlling the mixed weed population in oil palm plantation; glyphosate and glufosinate-ammonium showed greater effectiveness than paraquat. The herbicides, applied at their recommended rates, left no residual effects on the surrounding ecological components of oil palm plantation.

Key words: Herbicide efficacy, mixed weeds, young oil palm, paraquat, glufosinate-ammonium, glyphosate.

INTRODUCTION

The use of herbicides to control weeds is a common practice in oil palm plantation in Malaysia. A single most used broad spectrum herbicide (for over 40 years) was paraquat. The use of this herbicide, however, was halted in 2002 for the reasons of toxicity and hazards to human, but was lifted in 2006 to allow for more comprehensive studies. The disallowed use of paraquat left an open option to users for replacement. Several other common broad-spectrum herbicides, with different kind of activities and mode of actions, are available in the market. Among these herbicides are glufosinate-ammonium and glyphosate. All these herbicides are foliar applied, with paraquat

*Corresponding author. E-mail: rosli@agri.upm.edu.my. Tel: +603-89466924.

Abbreviations: NA, Nutrient agar; **PDA,** potato dextrose agar; **CFU,** colony formed unit.

activity been through contact (Turner and Gilbanks, 2003), glufosinate-ammonium been partially systemic (Collins, 1991) and glyphosate acts by systemic action (Chang and Liao, 2002). Individual reports on their usage, activities and effectiveness on different weed situations have been well recorded (Calderbank and Slade, 1975; Kuntom et al., 1999; Anderson et al., 1993; Horlein, 1994; Chang and Liao, 2002; Jordan et al., 1997), but their efficacy and environmental impact under one condition were never compared. This study evaluates after the effects of a single spray application, the comparative effectiveness and impact on some ecological factors when used to control mixed weed that were under oil palm situation.

MATERIALS AND METHODS

A field experiment was set up in a 2 year-old oil palm plantation of MAB Agriculture-Horticulture Sdn. Bhd., Sepang, Selangor, Malaysia. The experiment was laid out as randomized complete block design with 4 replications, and each plot measured 5 x 20 m^2 which included mixed (broadleaf and grass) weeds and 3 oil palm crop trees. The plots were sprayed at 200 L ha^{-1}, with field application recommended rates of paraquat (600 g a.i. ha^{-1}), glufosinate-ammonium (600 g a.i. ha^{-1}), glyphosate (1200 g a.i. ha^{-1}) and untreated control plots. The herbicide formulations used were Gramoxone^R (200 gL^{-1} paraquat, Syngenta Crop Protection), Basta 15^R (150 gL^{-1} glufosinate-ammonium, Bayer Cropscience) and Roundup^R (360 gL^{-1} glyphosate, Monsanto). Knapsack sprayer fitted with a 2.5 deflector nozzle was used for spraying. The experiment was repeated at different site within the same plantation and the results were combined.

Effects of herbicides on weed population

The effects of the herbicides on total weed population were measured as the percentage of weed killed, dry weight, growth reduction and duration of their effective control of the weeds relative to the control treatment. Square method was used to evaluate the parameters. Samples were taken by randomly placing a 50 x 50 cm quadrate at 3 locations in each experimental unit. Non-destructive sampling was done at 2 and 4 weeks after treatments (WAT) and the destructive sample was taken at 8, 12 and 16 WAT. The duration of effective control is taken as a period where a treatment is able to suppress weed growth more than 50%. The percent growth reduction is the ability of a treatment to suppress weed growth and is calculated using the formula (Chuah et al., 2004):

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

Effects of herbicide on crop plants

The effects of herbicide residues on oil palm development and production as the result of herbicide spraying to control weeds were determined based on the oil palm plant height, number of front and fruit bunch produced by each plant relative to the control treatment. Plant height and number of fronds were recorded for each crop plant within each plot at every 4 week intervals until 16 WAT. Plant height was measured from the soil surface to the highest part of fully opened frond. The number of frond was counted from the base of the fresh-green to the first fully-opened frond. The number of fruit bunches were recorded at 8 weeks interval beginning from the 16 until 32 WAT. Counts were made on bunches which had formed fruits.

Soil residual effects and determination

Residues were determined as the effect on soil microorganisms (bacteria and fungi); bioassay of phytotoxicity and total detectable residues in soil from the treated plots sampled at 2, 4, 8 and 16 WAT. The data were presented as relative to the control treatment. The dilution plate technique was used to enumerate the bacteria and fungi colonies, respectively, on nutrient agar (NA) and potato dextrose agar (PDA) medium. 10 g of each soil sample was diluted with sterile distilled water until 10^{-6} dilution for bacteria and 10^{-4} for the fungi. Colony counts were done from 0.1 ml aliquot on NA or PDA after incubation at room temperature (28 ± 2°C) for 4 days (bacteria) and 3 days (fungi). The number of colony per plate was multiplied by the dilution factor to obtain the total number of colony formed unit (CFU) per gram of soil (Chakravarty and Chatarpaul, 1990).

The bioassay technique of tracing the residues in soil was conducted using sensitive seedlings of corn and cucumber. The seeds were sown in 400 g of the collected soil samples in 9 cm polybeg (1 seed per beg). Germination and growth components (seedling height and total dry weight) were recorded after 14 days. Soil samples from the experimental plots at 2, 8 and 16 WAT, were subjected to the herbicides residue analysis. The extraction and clean-up procedures described by Worobey (1987) were followed. HCl and methanol were used for the extraction and the extractant was passed through LC-Si SPE tube for the clean-up. The solution was later centrifuged for 3 min, before injecting into HPLC for the detection of the residues. The analysis for paraquat was based on the procedure of Ouyang et al. (2004) using model 2996 photodiode array detector (PAD) (Waters, USA) and a 3.9 x 150 mm i.d. C_{18} analytical column (Waters, Ireland). Flow rate was set at 1 ml min^{-1} and detector wavelength at 257 nm. Glyphosate and glufosinate-ammonium were analyzed simultaneously using model 7125 manual injector with a 20 µm loop (Rheodyne, USA), with model 470 scanning fluorescence detector (Waters, USA) and a 250 x 4.6 mm i.d. SS EXSIL ODS 5 µm C_{18} analytical column (SGE, Australia). Limits of detection were 0.5 ppm for paraquat and glufosinate-ammonium and 0.1 ppm for glyphosate.

RESULTS AND DISCUSSION

The biological and residual impact of paraquat, glufosinate-ammonium and glyphosate at recommended field rates were compared to record the biological and environmental benefits among them. Paraquat, sprayed at 600 g a.i. ha^{-1} produced good efficacy, reaching maximum control (total weed killed) of 74% at 4 weeks after treatment (WAT) (Table 1). Acceptable control level was achieved until 12 WAT. The weed growth reduction was significant ($p < 0.05$) until 16 WAT, but the duration of effective control with more than 50% weed killed, was up to 8.8 weeks. Sign of recovery of the weeds was noticeable at 8 WAT. These measurements, however, were lower than those obtained for treatments with glufosinate-ammonium and glyphosate. Glufosinate-ammonium and glyphosate produced significantly better performance with a range of weed killed from 95 - 99% at

Table 1. Effects of broad-spectrum herbicides on weed development.

Effect on weeds	Treatment comparison (mean % relative to control)			
	Control	Paraquat (600 g ai ha^{-1})	Glufosinate-ammonium (600 g ai ha^{-1})	Glyphosate (1200 g ai ha^{-1})
Total killed (WAT)				
2	0[a]	74.1[b]	95.1[c]	98.8[c]
4	0[a]	74.1[b]	97.9[c]	99.7[c]
Dry weight (WAT)				
8	100[a]	45.9[b]	20.5[c]	19.2[c]
12	100[a]	54.5[b]	28.0[c]	29.6[c]
16	100[a]	82.3[a]	58.4[b]	55.1[b]
Growth reduction (WAT)				
8	0[a]	53.3[b]	78.1[c]	89.7[c]
12	0[a]	44.5[b]	71.3[c]	69.8[c]
16	0[a]	17.5[b]	41.5[c]	44.8[c]
Effective control period (week with >50% killed)	0[a]	8.8[b]	14.8[c]	14.8[c]

WAT: Week after treatment. Means within rows followed by the same letter were not significantly different at P<0.05 by DMRT.

2 WAT and 4 WAT. The weeds showed similar response to the 2 chemicals on the amount of dry weight recovered from 8 - 12 - 16 WAT. Reduced dry weight percentages for the 2 herbicides indicate slower response, in term of death of the weeds to the herbicides. The lowest dry weights recorded until the end of the sampling period of 16 WAT were 58.4 and 55.1%, respectively. These were significantly lower than that obtained for paraquat (82.3%).

Lower weed growth reduction when compared to the control indicated less efficacy of the chemical or when compared with earlier sampling period from 8 - 16 WAT. It also indicated weed recovery. It has been reported earlier that glufosinate-ammonium gave good to excellent weed control at 7 - 8 days after treatment (DAT) by stopping photosynthesis (Hoerlien, 1994; Riley et al., 2001). Glyphosate was effective in the control of annual and perennial weeds, with symptom of development slowed but irreversible (Collins, 1991), and the treated plants died in 1 - 3 weeks (Chang and Liao, 2002).

Paraquat, glufosinate-ammonium and glyphosate applied for weed control at recommended field application rates did not cause adverse effect on oil-palm crop development and production. No significant effect was detected for all treatments on the number of fronds, crop plant height and the number of fruit bunches recorded over 16 WAT (Table 2). The herbicides were never applied directly to the crop plants. The herbicide residues (if was present) in the soil, had no significant effect on the crop development and production. Effect on soil micro-organisms (bacteria and fungi) was also insignificant for all the herbicide treatments. Laboratory colony counts from soil sampled after treatments indicated negligible effect on the bacterial and fungi populations from the early counts at 2 WAT until late at 16 WAT (Table 3). The effects of paraquat, glufosinate-ammonium and glyphosate in soil had been described to be adsorption to soil components making it biologically unavailable and had been negligible to tolerable or of little toxic consequence to plants, earthworms and micro-organism (Smith and Mayfield, 1978; Kamrin, 1997).

Paraquat, glufosinate-ammonium and glyphosate treatment to control weeds at field recommended rates also did not leave detrimental level of residues in the soil. Detection of phytotoxic residues through bioassay with known sensitive crop plants of corn and cucumber showed no effect on germination and dry weight of the seedling sampled until 8 WAT (Table 3). The fact that the results obtained for the germination percentages and the seedling development responses were consistent over those sampling periods of 1 DAT and 1 or 2 WAT indicate several possibilities that the treatments with those herbicides did not leave biologically active residue, which could be loss or dissipated from the soil; the residues were adsorbed to the soil particles and become biologically inactive or unavailable to the plants or minimal amount of the residues were present and available to the plant at much lower than the dose required to produce an effect on seed germination and seedling development. No residues from the above treatments also showed that the plant response (seed germination and seedling growth) were consistent over the

Table 2. Effects of broad-spectrum herbicides on crop development.

Effect on crop part (WAT)	Treatment comparison (mean % relative to control)			
	Control	Paraquat (600 g ai ha^{-1})	Glufosinate-ammonium (600 g ai ha^{-1})	Glyphosate (1200 g ai ha^{-1})
Number of front				
0	100[a]	96.2[a]	87.9[a]	88.5[a]
4	100[a]	93.6[a]	85.2[a]	89.5[a]
8	100[a]	91.9[a]	86.4[a]	90.2[a]
16	100[a]	98.9[a]	95.8[a]	94.6[a]
Plant height				
0	100[a]	100[a]	92.3[a]	86.1[a]
4	100[a]	100[a]	92.1[a]	86.1[a]
8	100_a	99.7[a]	93.4[a]	87.2[a]
16	100[a]	100[a]	97.4[a]	90.7[a]
Number of fruit bunch				
16	100[a]	86.7[a]	88.6[a]	90.1[a]
24	100[a]	90.3[a]	100[a]	91.4[a]
32	100[a]	91.1[a]	100[a]	98.3[a]

WAT: Week after treatment. Means within rows followed by the same letter are not significantly different at P<0.05 by DMRT.

Table 3. Soil residual effects of broad-spectrum herbicides.

Residual characteristic effect	Treatment comparison (mean % relative to control)			
	Control	Paraquat (600 g ai ha^{-1})	Glufosinate-ammonium (600 g ai ha^{-1})	Glyphosate (1200 g ai ha^{-1})
Microorganism (WAT)				
Bacterial population				
2	100[a]	80.5[a]	94.7[a]	100[a]
4	100[a]	92.1[a]	100[a]	100[a]
8	100[a]	92.0[a]	98.5[a]	100[a]
16	100[a]	94.0[a]	93.7[a]	100[a]
Fungi population				
2	100[a]	100[a]	96.9[a]	100[a]
4	100[a]	94.9[a]	100[a]	95.3[a]
8	100[a]	96.9[a]	89.6[a]	96.6[a]
16	100[a]	97.9[a]	97.6[a]	95.2[a]
Phytotoxicity (bioassay)				
Corn				
Germination (2 WAT)	100[a]	97.9[a]	100[a]	95.8[a]
Seedling height (2 WAT)	100[a]	98.1a	100[a]	99.9[a]
Dry weight				
2 (WAT)	100[a]	100[a]	100[a]	100[a]
4 (WAT)	100[a]	90.5[a]	100[a]	100[a]
Cucumber				
Germination (2 WAT)	100[a]	97.9[a]	100[a]	100[a]
Seedling height (2 WAT)	100[a]	99.0[a]	100[a]	97.0[a]

Table 3. Contd.

Dry weight (WAT)				
2	100 [a]	98.9 [a]	100 [a]	100 [a]
4	100 [a]	93.6 [a]	98.5 [a]	94.9 [a]
Soil residue (ppm)				
2	*n.d.* [a]	0.95 [a]	*n.d.* [a]	0.13 [a]
8	*n.d.* [a]	0.88 [a]	*n.d.* [a]	0.14 [a]
16	*n.d.* [a]	0.59 [a]	*n.d.* [a]	0.06 [a]

WAT: Week after treatment; *n.d.*: non-detectable. Means within rows followed by the same letter were not significantly different at P<0.05 by DMRT.

whole period of study of up to 4 WAT.

Constenla et al. (1990) reported that the adsorption capabilities of various soils averages at 100 - 500 ppm, although, some soil have a capacity exceeding 1000 ppm and that paraquat was strongly adsorbed by treated soil, was not adsorbed by the crop and growth of corn seedlings was normal at 50 ppm treatment. Glufosinate-ammonium was reported not to induce phytotoxcity in soil, and that the DT_{50} in soil was of 3 - 10 days after application depending on soil condition (Hoerlein, 1994). Glyphosate is strongly adsorbed to most soil, even those with the lower organic and clay content, but readily bound to clay (Sprankle et al., 1975; Glass, 1987). It is moderately persistent in the soil environment with a field half-life of 47 days (Kamrin, 1997). It can be absorbed on clay as cation (by ion exchange) or by salt formation and growth of corn seedlings was normal at 500 ppm treatment (Sprankle et al., 1975). The actual residue detectable was also negligible from the earlier sample at 2 WAT until 16 WAT; amounting to no residue left in the soil. These results were supported by the residue analysis of soil from the same treatment plots conducted using HPLC. Insignificant amount of residues were detected until 16 WAT (Wahyu Wibawa, 2007). The range of residues detected for the higher treatment concentrations of those herbicides sampled at 2 and 16 WAT were 1.35 and 0.63 ppm (paraquat at 800 g a.i. ha^{-1}); 0.17 and 0.11 ppm (glyphosate at 1600 g a.i.ha^{-1}) and non-detectable (glufosinate-ammonium at 800 g a.i. ha^{-1}). A trend of less detectable amount over the period also indicated that minimal amount of residues were present and lost over time.

In conclusion, paraquat, glufosinate ammonium and glyphosate applied at recommended rates were effective in the control of the mixed weeds under young oil palms. Glufosinate-ammonium and glyphosate were more effecttive, achieving up to 95 - 99% killed with longer duration compared with paraquat. The herbicides caused no adverse effect on the ecological components of crops and soil microorganisms (bacteria and fungi) and left no detrimental level of residue in soil. Amount of actual detectable residue in soil was negligible.

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