Pertanika J. Trop. Agric. Sci. **33 (2)**: 233 - 241 (2010)
ISSN: 1511-3701

Efficacy and Cost-Effectiveness of Three Broad-Spectrum Herbicides to Control Weeds in Immature Oil Palm Plantation

Wahyu Wibawa[1], Mohd Ghazali Mohayidin[2*], Rosli B. Mohamad[3], Abdul Shukor Juraimi[3] and Dzolkhifli Omar[4]

[1]Balai Pengkajian Teknologi Pertanian Bengkulu, Indonesia
[2]Faculty of Business and Management, Open University Malaysia, 50480 Kuala Lumpur, Malaysia
[3]Department of Crop Science,
[4]Department of Plant Protection, Faculty of Agriculture, Universiti Putra Malaysia, 43400 UPM, Serdang, Selangor, Malaysia
**E-mail: mohd_ghazali@oum.edu.my*

ABSTRACT

Efficacy and cost-effectiveness of three herbicides (paraquat, glufosinate ammonium, and glyphosate) were evaluated at the MAB Agriculture-Horticulture Sdn. Bhd. Plantation, in Sepang, Malaysia from February 2004 to October 2005. The experimental design was RCBD with four replications. Each plot size, with the measurement of 4.8 x 20.5 m, was used for three oil palm plants. There were 13 treatments applied at the respective rates (namely, paraquat at 200, 400, 600, 800 g a.i. ha^{-1}, glufosinate ammonium at 200, 400, 600, 800 g a.i. ha^{-1}, glyphosate at 400, 800, 1200, 1600 g a.i. ha^{-1}) and an untreated check as a control. The rates for the herbicides cover their field recommended rates (paraquat at 400-600 g a.i. ha^{-1}, glufosinate ammonium at 500 g a.i. ha^{-}1, and glyphosate at 1000 g a.i. ha^{-}1). Results showed that glufosinate ammonium and glyphosate gave better efficacies than paraquat as revealed by the data on the percentage of weeds killed, the percentage of weed growth reduction and the duration of effective weed control. Nonetheless, a similar efficacy did not always produce the same cost-effectiveness. The most cost-effective treatment was glyphosate (at 400 g a.i. ha^{-1}), followed by glyphosate (at 800 g a.i. ha^{-1}) and glufosinate ammonium (200 g a.i. ha^{-1}) with the costs around RM108.95, RM160.70, and RM214.19 ha^{-1}year^{-1}, respectively. Meanwhile, glyphosate has the ideal criteria as the most cost-effective herbicide because it is cheap (at the current price of RM13.75 L^{-1}), good efficacy at low dose, produces long duration of effective weed control, and lesser spraying rounds required year^{-1}.

Keywords: Efficacy, cost-effectiveness, oil palm, herbicides

INTRODUCTION

Weed control is an important and expensive component of plantation crop management (Khairudin and Teoh, 1990). Azahari *et al.* (2004) stated that the cost incurred to control weed may account for 17 to 27 percent of the total upkeep cost in immature or mature oil palm. Herbicides are not problem-free, but there are many reasons why they are such a popular form of weed control (Esterninos and Moody, 1988). Among other, paraquat, glyphosate, and glufosinate ammonium are the most commonly used herbicides in oil palm plantation (Chung and Sharma, 1999; Madeley, 2003). In Malaysia, the use of herbicides in 2004 contributed to 67.49% of the total pesticides used, and herbicide use was predicted at 15.6 million

Received : 1 April 2009
Accepted: 27 January 2010
*Corresponding Author

litres in oil palm in 2005 (Malaysia Agricultural Directory and Index, 2003/2004).

Efficacy is the ability of pesticides to produce a desired effect on a target organism (Kamrin, 1997). Terms such as "mode of action", "injury", and "weed killed" should be well understood to avert improper perception. Sometimes, growers are confused with the use of the terms "injury" and "weed killed". So far, most applicators and growers have perceived efficacy based on the period required by herbicides to show injury on the controlled weeds. The efficacy alone is not enough to determine suitable herbicides in weed management. Cost-effectiveness of herbicides applied is another factor to be taken into consideration when making any decision. Orme (2001), and Turner and Gillbanks (2003) calculated the weed control cost ha^{-1} $year^{-1}$ by summing 3 or 4 cost components, including herbicide cost, labour cost, number of spray round $year^{-1}$, and water transport. According to Atkin and Leisinger (2000), growers prefer an effective herbicide with acceptable cost.

In order to determine how efficient a treatment is when it is applied, the efficacy and cost-effectiveness of each herbicide should be calculated. It is important to note that the treatments with good efficacy are not always the most cost-effective because efficiency is affected by many factors. The objective of the present study was to compare the efficiency of herbicides applied for general weed control in immature oil palm based on their efficacies and cost-effectiveness.

MATERIALS AND METHODS

Experimental Site and Treatments

In this study, two-year old oil palms were used for the experiment. Dominant weed species found in this area include broad-leaves (*Croton* sp., *Asystasia gangetica, Centrosema pubescen, Borreria latifolia, Hedyotis* verticillata) and narrow-leaves (*Paspalum commersonii. Pennisetum polystachyon, Eleusine indica, Digitaria ciliaris, Ischaemum* timorense) (Wibawa, 2007). The experimental design was RCBD with four replications. There were 13 treatments applied (namely, paraquat at 200, 400, 600, 800 g a.i. ha^{-1}, glufosinate ammonium at 200, 400, 600, 800 g a.i. ha^{-1}, glyphosate at 400, 800, 1200, 1600 g a.i. ha^{-1}, and an untreated check as a control). The rates of the herbicides used were inclusive of their recommended field application rates (i.e. paraquat 400-600 g a.i. ha^{-1}, glufosinate ammonium 500 g a.i. ha^{-1}, and glyphosate 1000 g a.i. ha^{-1}). The herbicide formulations used were Gramoxone® (200 g paraquat L^{-1}), Basta 15® (150 g glufosinate ammonium L^{-1}) and Roundup® (360 g glyphosate L^{-1}). Knapsack sprayer, fitted with AN 2.5 deflector nozzle, was used to deliver 200 L ha^{-1} of herbicide solution. In this study, blanket spray was applied for the experiment.

Efficacy

The square method was used to evaluate weed control as a result of herbicide application. The percentage of weed killed was calculated according to the method described in Alloub *et al*. (2000) and Pritchard (2002). Weeds killed meant that all tissues from the growing points to the soil surface were completely dead. The evaluation of weed dry weight, at 8, 12, and 16 weeks after the treatment (WAT), was done as described in Felix and Owen (1999), while the percentage of weed growth reduction was calculated using the method described in Lanie *et al*. (1993), Lanie *et al*. (1994), Murray *et al*. (1994), Utulu (1998), Pritchard (2002), and Chuah *et al*. (2004). The weed dry weight values, between the narrowest observations from 8 to 12, 12 to 16 WAT, were predicted using the regression. The formula used to calculate the reduction in the percentage of growth is as follows:

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

Whereby,

0 percent of growth reduction = no weed control

1-10 percent of growth reduction = very poor weed control

11-20 percent of growth reduction = poor weed control

21-30 percent of growth reduction = poor to deficient weed control

31-40 percent of growth reduction = deficient weed control

41-50 percent of growth reduction = deficient to moderate weed control

51-60 percent of growth reduction = moderate weed control

61-70 percent of growth reduction = weed control somewhat less than satisfactory

71-80 percent of growth reduction = satisfactory to good weed control

81-90 percent of growth reduction = very good to excellent weed control

91-100 percent of growth reduction = complete weed control

The duration of effective weed control is the period where a treatment was able to suppress weed growth, in term of weed dry weight, i.e. ≥50 percent relative to the untreated check. This characteristic was calculated based on the percentage of weed growth reduction values at 8, 12, and 16 WAT.

Meanwhile, the number of the actual spraying round/year refers to the re-spraying needed to get a satisfactory weed control. Note that the unit used for the duration of effective weed control is week and there are 52 weeks in a year.

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

Cost Effectiveness

The major operational costs to manage weeds include herbicide cost, labour cost, and the actual number of spray round/year. Thus, the cost for controlling weeds/ha/year can be formulated as follows:

Cost ha^{-1} year^{-1} = [(herbicide price L^{-1} x herbicide dose L ha^{-1}) + labour cost + water cost] x number of actual spraying round year^{-1}

Based on the survey data, the labour cost at the MAB plantation was RM15 ha^{-1}, while the capacity of workers ranged from 1 to 3 ha^{-1} man/day. Cost for water transportation was sometimes not computed as cost component because water supply is available in the field like ponds, streams, or drain water. For the current study, the price of herbicides was based on the price recorded in July 2005.

RESULTS AND DISCUSSION

Efficacy

Apparently, the percentages of weed killed, weed growth reduction, and duration of effective weed control were significantly affected by the treatments used (Table 1). The percentage of weed killed is good and important indicator to determine the efficacy of herbicide applied. In particular, the paraquat treatments were found to produce lower amount of weeds killed (50.94 – 82.58 percent), than the glufosinate ammonium and glyphosate treatments which destroyed around 91.55 – 97.97 percent and 95.78 – 100.00 percent of weeds, respectively (Table 1). These findings showed that the glufosinate ammonium and glyphosate herbicides are better or more efficient than paraquat in destroying weeds. The paraquat treatments at 200 and 400g ha^{-1} were not effective in controlling mixed weeds in immature oil palm because the ability to control weeds was below 70 percent. Burrill *et al*. (1976) stated that 70 percent of weed killed is the minimum acceptable level of control, while more than 90 percent weeds killed is an excellent level of control. Ashton and Crafts (1981) stated that paraquat is not considered to be selective herbicide, although broadleaf plants are injured somewhat more than grasses at a given low rate. Collins (1991) reported that paraquat has limited efficacy on perennial weeds, but it is more effective on weeds which are small and in early establishing or vegetative phase of growth. Some annual grasses may only be temporarily suppressed because the low and enclosed growing points are reached by the spray. Turner and Gillbanks (2003) stated that greatest paraquat efficacy is found where the weed species to be controlled have restricted root system or are still young.

Weed growth reduction reflects the capability percentage of a particular treatment to suppress weed growth relative to the untreated check. A higher percentage of weed growth reduction leads to a higher ability to suppress weed growth. As indicated earlier, paraquat has been found to reduce weed growth less efficiently than glufosinate ammonium and glyphosate, particularly at 8, 12, and 16 WAT (Table 1).

In this study, the treatments using paraquat produced shorter duration of effective weed control (i.e. within 4.00 – 11.75 weeks) than glufosinate ammonium and glyphosate which gave 14.50 – 15.00 weeks. Consequently, shorter duration of weed effective control leads to a more frequent spraying round/year (Table 1). In order to get satisfactory weed control, 4.44 – 13.04 of paraquat treatment spraying rounds year^{-1} are needed, whereas only 3.48 – 3.60 of spraying rounds year^{-1} are required when glufosinate ammonium is used. Kuan *et*

TABLE 1
The effects of paraquat, glufosinate ammonium, and glyphosate on the percentages of weeds killed, weed growth reduction, duration of effective weed control and spraying rounds year^{-1}

Treatment	Total weed killed (%)	Weed growth reduction (%)			Duration of effective weed control (weeks)	Spraying rounds year^{-1}
		8 WAT	12 WAT	16 WAT		
Untreated check	0.0 h	0.0 e	0.0 d	0.0 c	0.0 e	0.0
Paraquat 200 g ha^{-1}	50.9 g	26.9 d	38.2 c	12.4 b	4.0 d	13.0
Paraquat 400 g ha^{-1}	66.4 f	40.0 cd	38.8 c	11.6 b	6.0 d	8.7
Paraquat 600 g ha^{-1}	74.1 f	53.3 bc	40.6 c	17.5 b	8.8 c	6.0
Paraquat 800 g ha^{-1}	82.6 e	64.5 ab	49.8 b	20.2 b	11.8 b	4.4
Gluf. ammonium 200 g ha^{-1}	91.6 d	76.4 a	69.3 a	45.5 a	15.0 a	3.5
Gluf. ammonium 400 g ha^{-1}	95.3 cd	89.0 a	71.2 a	41.8 a	14.8 a	3.5
Gluf. ammonium 600 g ha^{-1}	97.9 bc	78.1 a	71.4 a	41.5 a	14.8 a	3.5
Gluf. ammonium 800 g ha^{-1}	98.0 bc	75.3 a	70.2 a	40.5 a	14.8 a	3.5
Glyphosate 400 g ha^{-1}	95.8 bc	76.9 a	69.6 a	40.0 a	14.5 a	3.6
Glyphosate 800 g ha^{-1}	100.0 a	81.4 a	70.7 a	39.6 a	14.8 a	3.5
Glyphosate 1200 g ha^{-1}	99.7 ba	79.7 a	69.8 a	44.8 a	14.8 a	3.5
Glyphosate 1600 g ha^{-1}	100.0 a	78.1 a	71.3 a	41.3 a	14.8 a	3.5

Means within the columns followed by the same letter are not significantly different at 5 percent by the DMRT *al*. (1991) reported that the number of spraying rounds year^{-1} for weed control in immature oil palm (<3 year old) ranged from 5 to 6.67 rounds, while Chung and Sharma (1999) reported that the frequency of weeding ranged from 4 to 6 round year^{-1}.

The spraying round/year has a close relationship with the efficacy of herbicides applied (Table 1). In more specific, the efficacy of glufosinate ammonium and glyphosate treatments was apparently much better than the paraquat treatments; their uses in the treatments increase the duration of effective weed control and reduce the number of spraying rounds year^{-1}.

Meanwhile, there is a positive correlation and regression between the percentages of weeds killed and weeds growth reduction (*Fig. 1*). The increase in the percentage of weeds killed is always followed by the increase in the percentage of weed growth reduction.

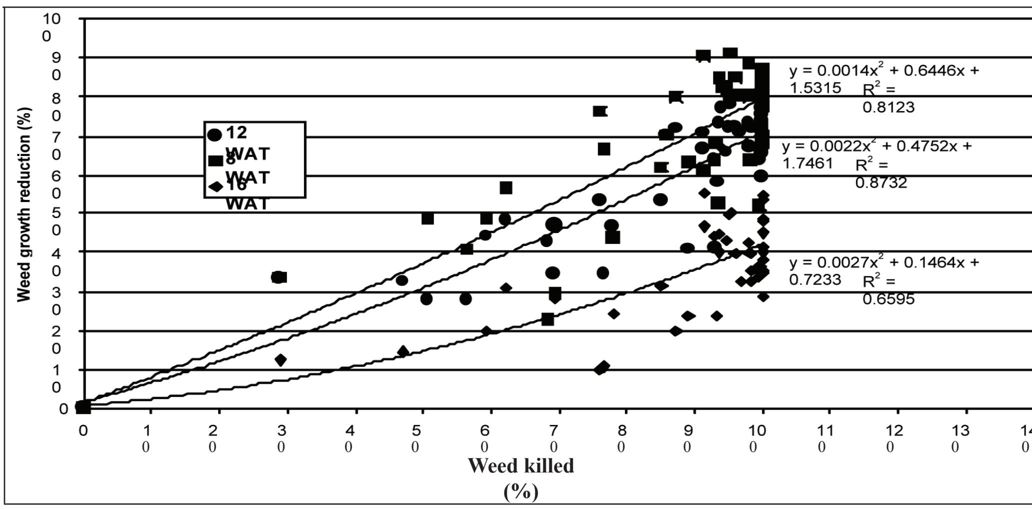

Fig. 1: Regression of the percentage of weed growth reduction on the percentage of weeds killed (same data were used in Rosli Mohamad et al., 2010. Pertanika J. Trop. Agric. Sc. 33(2): 193, same issue)

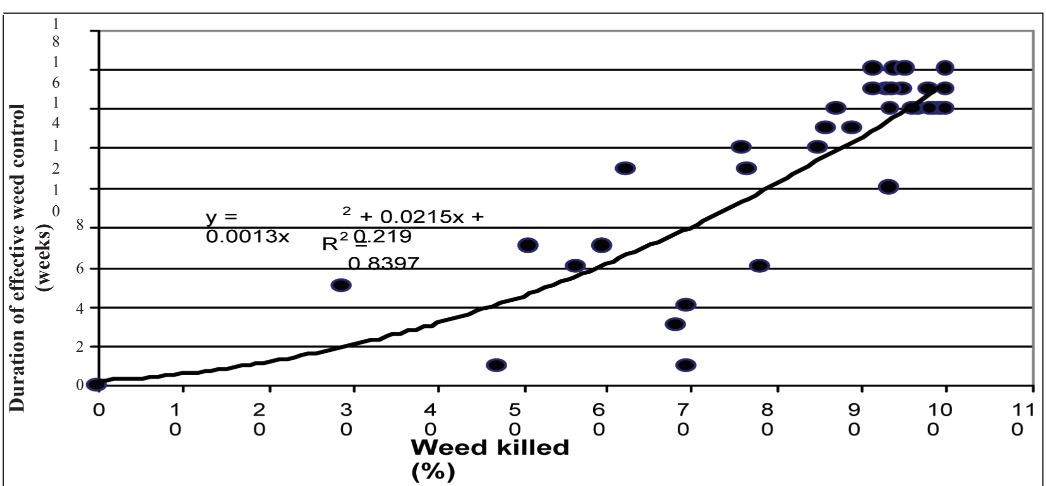

Fig. 2: Regression of the duration of effective weed control on the percentage of weed killed (same data were used in Rosli Mohamad et al., 2010. Pertanika J. Trop. Agric. Sc. 33(2): 193, same issue)

TABLE 2
The costs of paraquat, glufosinate ammonium and glyphosate in weed management ($RM\ ha^{-1}\ year^{-1}$)

Treatments (herbicides)	Herb. Dose (Lha^{-1})	Herb. price (RM/L)	Herb. Cost/ ha /round	Labour Cost/ ha /round	Duration (weeks)	Round /year	Cost/ ha/ round (RM)	Cost ha/ year (RM)
200 g paraquat./ha	1.0	13.8	13.8	15.0	4.0	13.0	28.8	374.7
400 g paraquat/ha	2.0	13.8	27.5	15.0	6.0	8.7	42.5	369.3
600 g paraquat/ha	3.0	13.8	41.3	15.0	8.8	6.0	56.3	335.1
800 g paraquat/ha	4.0	13.8	55.0	15.0	11.8	4.4	70.0	310.8
200 g gluf. Amm/ha	1.3	35.0	46.6	15.0	15.0	3.5	61.6	214.2
400 g gluf. Amm./ha	2.7	35.0	93.5	15.0	14.8	3.5	108.5	382.8
600 g gluf. Amm./ha	4.0	35.0	140.0	15.0	14.8	3.5	155.0	547.2
800 g gluf. Amm./ha	5.3	35.0	186.6	15.0	14.8	3.5	201.6	711.5
400 g glyphosate/ha	1.1	13.8	15.3	15.0	14.5	3.6	30.3	109.0
800 g glyphosate/ha	2.2	13.8	30.5	15.0	14.8	3.5	45.5	160.7
1200 g glyphosate/ha	3.3	13.8	45.8	15.0	14.8	3.5	60.8	214.6
1600 g glyphosate/ha	4.4	13.8	61.1	15.0	14.8	3.5	76.1	268.5

These are indicated by regression equations and their R-square values, namely 0.87, 0.81, and 0.66 at 8, 12, and 16 WAT, respectively. The independent variables were found to be significant at the probability levels of <0.05. These results prove that the treatments which produce poor efficacy can cause weeds to grow and recover in a short time.

Meanwhile, the percentage of weeds killed could also be used to predict the duration of effective weed control because it has significant positive correlation and regression (*Fig. 2*). In other words, a higher percentage of weeds killed leads to a longer duration of effective weed control, as indicated by the values of regression equation ($y = 0.0013x^2 + 0.0215x + 0.219$) and R-square (0.84). In this equation, the independent variables are also significant at the probability levels of < 0.05. The treatments with poor efficacy (i.e. low percentage of weeds killed) produce shorter effective weed control duration. On the contrary, longer weed control duration leads to lesser actual number of spraying rounds required per year. These findings indicate that the percentage of weeds killed plays an important role in evaluating the efficacy of herbicides applied because it has been found to affect the percentage of weed growth reduction, the duration of effective weed control, and spraying round/year.

Cost Effectiveness

The cost effectiveness of herbicides applied is not only affected by their efficacy but also by the dose and price of the herbicides applied. In this case, glufosinate ammonium was found to be the most effective herbicide and a longer duration

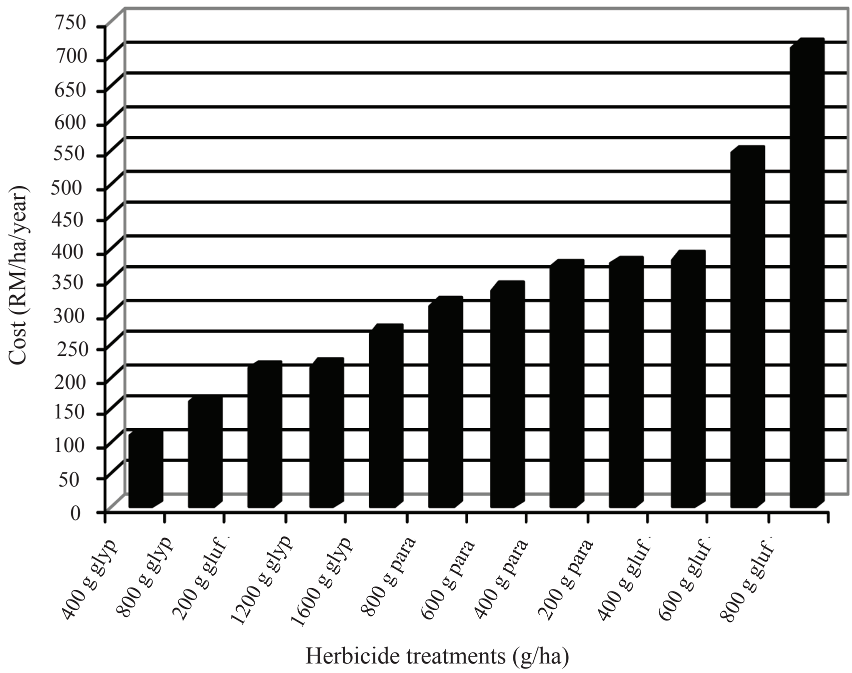

Fig. 3: Ranked cost of paraquat, glufosinate ammonium and glyphosate in controlling weed in immature oil palm (RM/ha/year)

of effective weed control, but it is not the most cost effective herbicide because the price is rather high (i.e. RM35.00 L^{-1}). On the other hand, paraquat is relatively cheap (RM13.75 L^{-1}) but not effective to control weeds, and its duration of control is also relatively shorter than that of glufosinate ammonium and glyphosate. The most cost effective herbicide with a good efficacy at a low dose used in the treatments should be cheap and produce a longer duration of weed control, as indicated by lesser spraying rounds required per year (Table 2 and *Fig. 3*). At 400g a.i. ha^{-1}, glyphosate was found to be the most cost effective pesticide for weed treatment (RM108.95 ha^{-1} $year^{-1}$), followed by glyphosate at 800g a.i. ha^{-1} (RM160.70 ha^{-1} $year^{-1}$), and glufosinate ammonium at 200g a.i. ha^{-1} (RM 214.19 ha^{-1} $year^{-1}$).

CONCLUSIONS

In short, glufosinate ammonium and glyposate produce better efficacies than paraquat, as indicated by the percentage of weeds killed, the percentage in the reduction of weed growth and the duration of effective weed control. Meanwhile, a similar efficacy does not always produce the same cost-effectiveness. The most cost effective treatment was produced by glyphosate at 400 g a.i. ha^{-1}, and was followed by glyphosate (at 800 g a.i. ha^{-1}) and glufosinate ammonium (at 200 g a.i. ha^{-1}) which cost RM108.95, RM160.70 and RM214.19 ha^{-1} $year^{-1}$, respectively.

ACKNOWLEDGEMENTS

The authors wish to express their appreciation to the Agency for Agricultural Research and Development (AARD) of the Department of Agriculture, Indonesia, particularly the Participatory Development of Agricultural Technology Project (PAATP, Asian Development Bank Loan) for funding this study. The authors are also grateful to the Faculty of Agriculture, UPM, for all facilities provided. Special thanks also go to the Managers of MAB-Agricultural-Horticulture Sdn. Bhd., for the permission given to conduct the experiment in the oil palm plantation area.

REFERENCES

Alloub, H.E., Amartalingam, R. and Mohamad, R. (2000). Oil palm empty fruit bunch fiber mats for weed control. *Journal of Plant Protection in the Tropics*, *13*(1), 23-31.

Ashton, F.M. and Crafts, A. S. (1981). *Mode of Action of Herbicides*. New York: John Wiley & Sons.

Atkin, J. and Leisinger, K.M. (2000). *Safe and Effective Use of Crop Protection Products in Developing Countries*. New York: CABI Publishing.

Azahari, M., Samingin, I. and Seman, I.A. (2004). Weed management. In E.A. Ghani, Z.Z. Zakaria and M.B. Wahid (Eds.), *Oil palm cultivation in Malaysia*. Selangor: MPOB.

Burrill, L.C., Cardenas, J. and Locatelli, E. (1976). *Field Manual for Weed Control Research*. Oregon: International Plant Protection Center Oregon State University.

Chuah, T.S., Salmijah, S. and Ismail, B.S. (2004). Efficacy of tank-mix combination of glyphosate and gramicides on the control glyphosate resistant and susceptible biotypes of goosegrass (*Eleusine indica*) (L.) (Gaertn.). *Plant Protection Quarterly*, *19*(4), 130-133.

Chung, G.F. and Sharma. (1999). Integrated pest and disease management and associated impact of pesticides. In Gurmit Singh, L.K. Huan, D.L. Kow and T. Leng (Eds.), *Oil palm and the environment* (pp 83-108). Kuala Lumpur: Malaysian Oil Palm Growers' Council.

Collins, S.C. (1991). Chemical control of grassy weeds. In F.W.G. Baker and P.J. Terry (Eds.), *Tropical grassy weeds* (pp. 73-84). UK: CAB. International.

Estorninos, L.E. and Moody, K. (1988). Evaluation of herbicides for weed control in dry-seeded wetland rice (*Oryza sativa*). *Philippine Journal of Weed Science*, *15*, 50-58.

Felix, M. and Owen, M.D.K. (1999). Weed population dynamics in land removed from the conservation reserve program. *Weed Science*, *47*, 511 – 517.

Kamrin, M.A. (1997). *Pesticide Profiles: Toxicity, Environment Impact, and Fate*. New York: CRC Press.

Khairudin, H. and Teoh, C.H. (1990). Evaluation of new herbicides for general weed control in young oil palm. In J. Sukaimi and M.T. Dolmat (Eds.), *Proceeding Palm Oil Development Conference*.

Kuan, C.Y., Ann, L.S., Ismail, A.A., Leng, T., Fee, C.G. and Hashim, K. (1991). Crop loss by weeds in Malaysia. In S.A.Lee and K.F. Kon (Eds.), *Proceeding of the third Tropical Weed Science Conference* (pp 1-21). Kuala Lumpur: MAPPS.

Lanie, A.J., Griffin, J.L., Reynolds, D.B. and Vidrine, P.R. (1993). Influence of residual herbicide on rate of paraquat and glyphosate in stale seedbed soybean (Glycine max). *Weed Technology*, *7*, 960-965.

Lanie, A.J., Griffin, J.L., Vidrine, P.R. and Reynolds, D.B. (1994). Weed control with non-selective herbicides in soybean (*Glicine max*) stale seedbed culture. *Weed Technology*, *8*, 159-164.

Madeley, J. (2003). Paraquat – syngenta's controversial herbicide. BD; PAN-UK;PAN-AP. http://www.pan-org.

Malaysia Agricultural Directory and Index. (2003/2004). Major Agricultural Commodities. Agriquest and UMAGA. Kuala Lumpur, Malaysia.

Malaysian Crop Care and Public Health Association. (2005). Annual Report, Kuala Lumpur, Malaysia.

Murray, M.W., Arnold, R.N., Gregory, E.J. and Smeal, D. (1994). Early broadleaf weed control in potato (*Solanum tuberosum*) with herbicides. *Weed Technology*, *8*, 165-167.

Orme, A. (2001). *Evolving a New Estate Practice for Circle and Path Spraying*. Malaysia: Aventis.

Pritchard, G.H. (2002). Evaluation of herbicides for the control of the environmental weed bridal creeper (*Asparagus asparagoides*). *Pant Protection Quarterly*, *17*(1), 17-25.

Turner, P.D. and Gillbanks, R.A. (2003). *Oil Palm Cultivation and Management*. Kuala Lumpur: The Incorporated Society of Planters.

Utulu, S.N. (1998). Controlling regrowth of *Chromolaena odorata* in immature oil palm. NIFOR. Benin city. Nigeria.

Wibawa, W. (2007). Efficacy, cost-effectiveness and risk-benefit analysis of three herbicides in immature oil palm plantation. Doctor of Philosophy Thesis, Universiti Putra Malaysia.