

The Potential Use of Oil Palm Frond Mulch Treated with Imazethapyr for Weed Control in Malaysian Coconut Plantation

(Potensi Penggunaan Sungkup Pelepah Kelapa Sawit yang Dirawat dengan Imazethapyr
untuk Mengawal Rumpai Ladang Kelapa di Malaysia)

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ABSTRACT

Introduction of new weed management strategy for coconut plantation in Malaysia is essential since the current weed control methods are less effective and highly herbicide dependent, thus leading to development of herbicide resistance in weeds as well as environmental and human health concerns. Thus, the present study aimed to evaluate the phytotoxic effects of oil palm frond mulch treated with imazethapyr at a reduced rate on weed emergence and growth. The results of glasshouse experiments have shown that imazethapyr at 12 g a.i. ha⁻¹ in combination with oil palm residues of leaflet (OPL), rachis (OPR) or frond (OPF) at rates of 1.4-1.8 t ha⁻¹ inhibited Eleusine indica emergence and growth by 90-100%, implying that imazethapyr is compatible with oil palm residue mulches. In the field experiment, hand weeding followed by OPF at 3.4 t ha⁻¹ treated with imazethapyr at 24 g a.i. ha⁻¹ have demonstrated excellent control of Mikania micrantha, Asystasia gangetica, Phyllanthus amarus, Panicum sp. and Echinochloa colona by reducing their total dry weight up to 95% at three months after treatment. The present results suggested that the integration of chemical, physical and mechanical methods can provide effective weed control in the coconut plantation for months.

Keywords: Coconut plantation; imazethapyr; Malaysia; mulch-herbicide interaction; oil palm frond

ABSTRAK

Pengenalan strategi pengurusan rumpai baharu untuk ladang kelapa di Malaysia adalah penting memandangkan kaedah kawalan rumpai sedia ada kurang berkesan dan sangat bergantung kepada racun rumpai, sekaligus membawa kepada pembangunan daya tahan racun rumpai ke atas rumpai serta kebimbangan kepada alam sekitar dan kesihatan manusia. Oleh itu, kajian ini bertujuan untuk menilai kesan fitotoksik sungkup pelepah kelapa sawit yang dirawat dengan imazethapyr pada kadar yang lebih rendah untuk mengawal kemunculan dan pertumbuhan rumpai. Keputusan uji kaji rumah kaca telah menunjukkan bahawa imazethapyr pada 12 g a.i. ha⁻¹ yang dicampur dengan sisa anak daun kelapa sawit (OPL), rakis (OPR) atau pelepah (OPF) pada kadar 1.4-1.8 t ha⁻¹ merencat kemunculan dan pertumbuhan Eleusine indica sebanyak 90-100%, yang menunjukkan bahawa imazethapyr adalah serasi dengan sisa sungkup kelapa sawit. Dalam kajian lapangan, merumput diikuti OPF pada kadar 3.4 t ha⁻¹ yang telah dirawat dengan imazethapyr pada 24 g a.i. ha⁻¹ menunjukkan kawalan yang cemerlang untuk Mikania micrantha, Asystasia gangetica, Phyllanthus amarus, Panicum sp. dan Echinochloa colona dengan berkurangnya jumlah berat kering sehingga 95% selama tiga bulan selepas rawatan. Keputusan kajian ini mencadangkan bahawa integrasi kaedah kimia, fizikal dan mekanik berkesan mengawal rumpai di ladang kelapa untuk berbulan-bulan lamanya.

Kata kunci: Imazethapyr; interaksi sungkupan-racun rumpai; ladang kelapa; Malaysia; pelepah kelapa sawit

INTRODUCTION

Coconut (*Cocos nucifera* L.) is tropical perennial crop and the fourth important industrial crop after oil palm, rubber and rice in Malaysia (Hairuddin et al. 2010). There are about 88,093 hectares of coconut planted area in Malaysia with a production of 595,097 tonnes per metric in 2014 (DOA 2015). In immature coconut plantations, vacant space between palms creates opportunities for weeds to grow ubiquitously (Liyanage & de Liyanage 1989). As a result, a wide range of perennial and annual weed species invade the non-utilized space. Weed infestation is a serious problem in coconut plantation where it is often difficult to control and disturb routine plantation management

systems such as manuring, harvesting and collection of nuts (Dilipkumar et al. 2017). Besides, weeds compete with coconut palms for soil moisture, nutrients and sometimes light, especially when the palms are in the seedling stage. In the event of prolonged dry periods, competition for soil moisture may considerably affect the coconut yield (Liyanage & de Liyanage 1989). Gunathilake (1993) stated that weed competition can result in coconut yield reduction up to 18-20%. Similarly, based on the cumulative average yield of coconut for three consecutive years in Sri Lanka, Samarajeewa et al. (2004) concluded that weed infestation may cause up to 54% reduction in coconut yield. To date, there are no published data on the effect of weeds on

coconut yields in Malaysia. However, the cost of weed management has contributed approximately 15-20% of the total cost of coconut production, implying that there is an urgent need to introduce effective and economically viable weed control strategies for coconut growers in Malaysia (DOA 2007).

Various means including mechanical, chemical and cultural methods can be employed for weed control in coconut plantation, however, the use of synthetic herbicides or chemical control is the most common (Senarathne et al. 2003). Complete eradication of weeds by using chemical method is not expected in plantation crop and weeds have to be managed to some extent so that they do not compete with coconut. Moreover, the increasing dependence on herbicides for weed control has led to environmental hazard, human health problems due to their persistent nature and weed resistance (Singh et al. 2006). Therefore, alternative weed control methods are emphasized. Organic mulch by using crop residues is increasingly popular because it has a number of advantages in cropping system (Jodaugiene et al. 2006). For instance, it provides a better soil environment by conserving soil moisture, increases organic matter contents as well as nutrient availability to crops while maintaining soil fertility and inhibiting weed growth in crop fields (Iyagba et al. 2012; Uwah & Iwo 2011). Besides, herbicide-treated organic mulches could offer a distinct advantage for weed control over untreated mulch. Mathers (2003) reported that herbicide-treated bark was able to provide a 1.5- and 1.8-fold increase more efficacy compared to the herbicide and bark residue applied alone, respectively. Moreover, 2.8 times increase in duration of efficacy and 22 times reduction in phytotoxicity if compared to the herbicide alone treatment. On the other hand, Case and Mathers (2006) reported that the herbicide-treated mulch could reduce the amount of herbicide applied per year while increasing application uniformity. They have indicated a significant interaction between herbicide and organic mulch that lead to the long term weed control.

In the landscape maintenance industry, it is common to apply herbicide-treated mulch to landscape beds to provide long-term and broad spectrum weed control (Case & Mathers 2006). However, no researches have been conducted to evaluate the herbicide-treated mulch

prospect for weed management in plantation crops like coconut. In Malaysia, this is the first study designed to address interaction between herbicide and organic mulch. Therefore, this study aimed to evaluate phytotoxic effects of oil palm frond mulch treated with imazethapyr for weed control in coconut plantation. Oil palm frond residue was selected as organic mulch based on its availability of material resources throughout the year and potential to inhibit weed emergence and growth up to 85-100% (Dilipkumar et al. 2015; Khalid et al. 1999). Furthermore, utilization of pruned oil palm fronds are only limited by stacking around the base of the oil palm trees and across the slope as mulching material to improve soil fertility and reduce soil erosion (Moraidi et al. 2012). While imazethapyr was selected because its synergistic combination effect with oil palm frond residue was proven in our preliminary study (unpublished data).

MATERIALS AND METHODS

EXPERIMENTAL SITE

Glasshouse experiments were conducted at the School of Food Science and Technology, Universiti Malaysia Terengganu, Terengganu, Malaysia (5.24°N, 103.05°E). The field experiment was conducted starting from December 2013 to April 2014 in a coconut plantation at MARDI station, Hilir Perak, Malaysia (3° 53' 42"N; 100° 52' 0"E). Temperatures and rainfalls of the experimental site are stated in Table 1.

HERBICIDE AND PLANT MATERIALS

Commercial grade of imazethapyr (Imaz 5.2 SL, 5.2%) was purchased from Farmcochem Sdn. Bhd. Selangor, Malaysia, whereas glyphosate isopropylamine (Sentry, 41%) was purchased from CP manufacturing Sdn. Bhd. Selangor, Malaysia. Goosegrass (*Eleusine indica*) seeds were collected from a wasteland of Gong Badak, Terengganu, Malaysia (5° 24' 19"N; 130° 05' 16"E). The seeds were scarified with sand papers and soaked in 0.2% potassium nitrate solution for 24 h before being used. A preliminary viability test was conducted and confirmed that germination rate of the seeds had more than 90%. Fresh and fully expanded oil palm (*Elaeis guineensis* var. Tanera)

TABLE 1. Meteorology data from December 2013 to April 2014 at the experimental site of MARDI station, Hilir Perak, Malaysia

	Dec. 2013	Jan. 2014	Feb. 2014	Mar. 2014	Apr. 2014
Monthly rainfall (mm)	337.4	149.7	142.2	123.4	128.1
Maximum temperature (°C)	33.5	33.0	34.5	35.4	34.2
Minimum temperature (°C)	24.9	24.5	25.0	25.0	25.0
Average temperature (°C)	27.5	27	27.7	28.4	28.4
No. of rainy days (Day)	21	9	3	8	14
Highest 24 h rainfall (mm)	84.2	80.1	34.2	38.4	56.5

fronds were collected from an oil palm plantation of the Federal Land Development Authority (FELDA) Chalok Barat, Terengganu, Malaysia (5°33'17"N; 102°43'17"E). The fronds were harvested from 35-years old oil palm trees; they were cut into small pieces with 6-10 cm length using a chopper machine (DISK MILL FFC-23, Shandong JimoHairong Machinery Co. LTD) and dried under direct sunlight at the glasshouse for one month. After completely dried, the fronds (OPF) were divided into two groups; one group was ground into powder forms (< 2 mm) using a mill (Nez ZFJ-200, Jiangsu, China), while the other group was separated into leaflet (OPL) and rachis (OPR) before ground. All the residue powders were stored at room temperature (27°C) until use.

DOSE-RESPONSE TEST OF OIL PALM RESIDUE MULCHES AND IMAZETHAPYR

Moist silt loam soil of 45 g (21% clay, 52.6% silt and 25.6% sand, pH4, organic carbon 1.6%) was filled in a plastic cup (4.5 diameters × 5 cm height) with holes at the bottom. Then, the cup was placed in a 40 × 30 × 5 cm tray and water was applied from the bottom of the cup to stimulate moist condition for proper growth of goosegrass seedlings under glasshouse conditions. Twenty goosegrass seeds were sown onto soil surface. The cups were then subjected to oil palm residue powders of OPL, OPR or OPF at 0.7, 1.5 and 3 t ha⁻¹, respectively, or imazethapyr at 1.9, 3.8, 7.5, 15, 30 and 60 g a.i. ha⁻¹, respectively, where the recommended rate is 240 g a.i. ha⁻¹ at one day after sowing the seeds. Imazethapyr treatments were applied using a micropipette (Eppendorf, Germany) at a spray volume of 450 L ha⁻¹. Meanwhile, untreated soil moistened with distilled water was used as a control. Number of emerged goosegrass seedlings was counted and recorded. Meanwhile, the shoot fresh weight of goosegrass was determined by harvesting and weighing the remaining aboveground tissues of each seedling at one month after treatment. Seedlings were considered emerged when the plumule lengths were > 2 mm (ISTA 1993). The data were expressed as percentages of their respective controls.

PHYTOTOXICITY OF IMAZETHAPYR-TREATED OIL PALM RESIDUE MULCH

The rates of oil palm residues or imazethapyr which provided 50% inhibition (ED₅₀) of goosegrass emergence obtained from the dose-response test were further examined in this experiment. Oil palm residues of OPL, OPR and OPF mulches at their respective ED₅₀ rates were treated with the ED₅₀ rate of imazethapyr by using a compression sprayer (Matabi Style 7; Goizper, Bergara, Spain) with a flat-fan nozzle, delivering a spraying volume of 450 L ha⁻¹ at 200 kPa. The oil palm residues were dried for 24 h under glasshouse conditions. Each type of herbicide-treated oil palm residue mulch was applied evenly onto the soil surface one day after 20 goosegrass seeds were sown

for each cup. One month after treatment, the number of seedling emergence was counted and shoot fresh weight was measured. Seedlings were considered emerged when the plumule lengths were >2 mm. The data were expressed as percentages of their respective controls.

FIELD EXPERIMENT

The experimental plots were established in the 5 years-old coconut plantation where coconut palms of hybrid variety, Cameroon Red Dwarf x Catigan Dwarf (CRD X CAT) have been planted since November 2008. A distance of 8.5 m between coconut rows and 8.5 m between coconut palms in rows was used, resulting in a density of 168 coconut trees per hectare. The experiment area consisted of ten coconut rows (85 m length × 76.5 m width), corresponding to 114 coconut palms in an area of 6503 m². Each plot measuring 10.2 m² of an area with 3.6 m diameter under the canopy of coconut tree was established. A total of eight treatments including untreated plots were carried out in the canopy area of coconut trees as follows: (T1) control (weed free), where weeds were not controlled by any treatments, (T2) slashing, where weedy plants were cut at 5 to 10 cm height by using a brush cutter (Mitsubishi TL33 engine); clipped vegetation was left on the plots, (T3) chemical control, where the application of glyphosate at a rate of 1.83 kg a.i. ha⁻¹ was carried out, (T4) slashing followed by glyphosate treatment at a rate of 1.83 kg a.i. ha⁻¹. The weedy plants were left for two weeks before herbicide application, (T5) hand weeding, where weedy plants were eliminated manually by hoeing, garden rake and by hand pulling. Pulled weedy plants were bagged and removed from the site, (T6) hand weeding followed by application of oil palm frond mulch at 4 t ha⁻¹, (T7) hand weeding followed by imazethapyr-treated oil palm frond (OPF) (12 g a.i. ha⁻¹ imazethapyr plus 1.7 t ha⁻¹ OPF residue powder) and (T8) hand weeding followed by imazethapyr-treated OPF mulch (24 g a.i. ha⁻¹ imazethapyr plus 3.4 t ha⁻¹ of OPF residue powder). In the chemically weeded plots (T3-T4), glyphosate was applied using a knapsack sprayer (Dofra, Malaysia) with a flat-fan nozzle, delivering a spraying volume of 1100 L ha⁻¹ at 200 kPa. Generally, there was no rain for 5-6 h after applying glyphosate. For T6-T8 treatments, water was applied by using a knapsack sprayer to deliver 6 L of water per treatment onto the soil surface at an area of 10.2 m² before mulch treatments were applied by hand. Weed density and weed dry weight were evaluated at three months after treatment by placing two quadrates (1 × 1 m) randomly in each plot. Five common weed species including *Asystasia gangetica*, *Echinochloa colona*, *Mikania micrantha*, *Panicum* sp. and/or *Phyllanthus amarus* appeared in each quadrate were cut at ground level and separated by weed species. Then, the weed samples were washed with tap water and counted to obtain weed density. The dry weight was determined after drying the weed samples in the glasshouse for three weeks to achieve constant weight.

STATISTICAL ANALYSIS

The dose-response test of imazethapyr and oil palm frond experiments were arranged in completely randomized designs with five replications. All the data were fitted to a logistic regression model, as follows (Kuk et al. 2002):

$$Y = d / (1 + [x/x_0]^b)$$

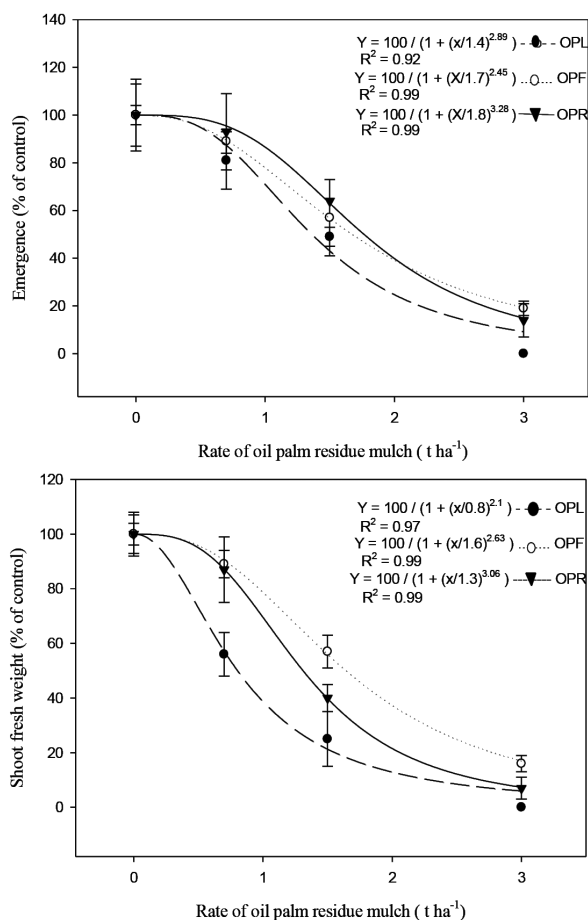
where Y is percentage of goosegrass emergence/shoot fresh weight; d is the coefficients corresponding to the upper asymptotes; x is the oil palm residue mulch or imazethapyr rate; x_0 is oil palm residue mulch or imazethapyr rate required to inhibit the goosegrass emergence/shoot fresh weight by 50% relative to control; and b is the slope of the line.

All the data were expressed as percentages of their respective controls. The phytotoxicity of imazethapyr-treated oil palm residue mulch test was arranged in a completely randomized design with five replications. The percentage data of goosegrass shoot fresh weight were checked for homogeneity of variance before being subjected to one-way analysis of variance (ANOVA). Means were separated using the Tukey test at 5% of significant level. Meanwhile, the percentage data of goosegrass emergence were subjected to Kruskal Wallis test and means were separated using the Dunn's Multiple Comparison Test. The field experiment was arranged in a randomized complete block design (RCBD) with three replications. The data were subjected to one-way analysis of variance (ANOVA). Since the block factor was not significantly different, data were pooled and combined. Data of weed density and weed dry weight were checked for homogeneity of variance test before being subjected to ANOVA. Total density data, density data of *Asystasia gangetica*, total dry weight data, dry weight data of *A. gangetica*, *E. colona* and *M. micrantha*, were subjected to $\sqrt{(x+0.5)}$ transformation, while dry weight data of *Panicum* sp. and total dry weight data were subjected to arcsine square root transformation and $\log(x+1)$ transformation, respectively, before being subjected to ANOVA. Then, the Tukey test was used to compare the mean among treatment at 5% of significant level. Density data of *E. colona* and *Panicum* sp. and dry weight data of *P. amarus* were subjected to non-parametric Kruskal Wallis test, followed by Dunn's Multiple Comparison Test.

RESULTS

SINGLE APPLICATION OF OIL PALM RESIDUE MULCHES OR IMAZETHAPYR

A series rate of oil palm residue mulches was set in the range of 0.75 to 3.0 t ha⁻¹ in dose response experiments. Both goosegrass seedling emergence and shoot fresh weight declined progressively with an increase of oil palm residue mulch rate, with OPL mulch produced higher phytotoxic effect to goosegrass plants (Figure 1). In

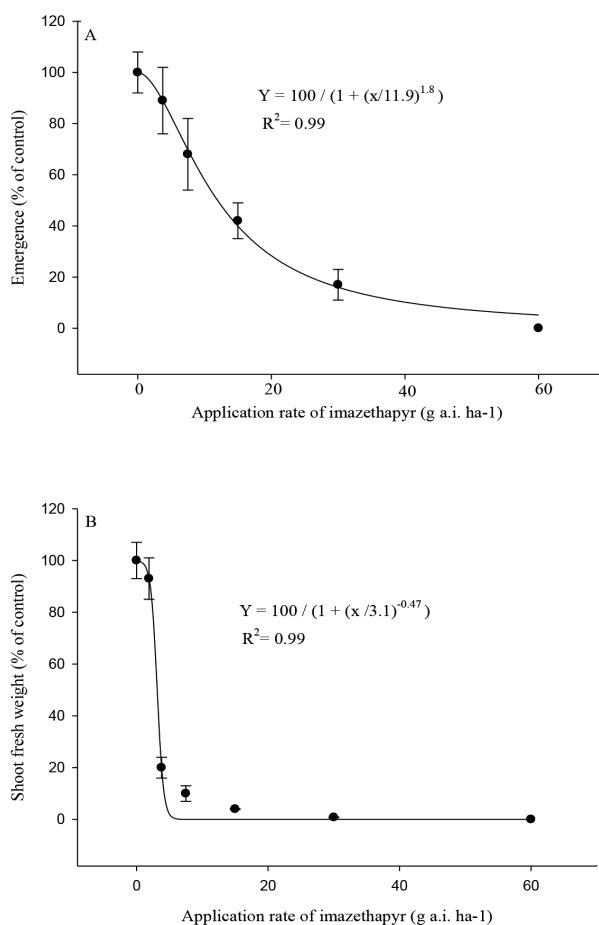


Vertical bars represent ± standard deviation of mean

FIGURE 1. Effects of pre-emergence application of oil palm residue mulch of leaflet (OPL), frond (OPF) or rachis (OPR) alone on emergence (a) and shoot fresh weight (b) of goosegrass in Kangkong series soil

contrast, at a rate of 0.75 t ha⁻¹, OPF had stimulatory effect on the goosegrass seedling emergence. It is noted that the rates required for 50% reduction (ED₅₀) of goosegrass emergence were 1.4, 1.8 and 1.7 t ha⁻¹ when being subjected to OPL OPR and OPF mulches, respectively. On the other hand, 0.8, 1.3 and 1.6 t ha⁻¹ of OPL, OPR and OPF mulch were needed respectively, to provide 50% inhibition of goosegrass shoot fresh weight.

The response of goosegrass seedlings to pre-emergence application of imazethapyr at one month after treatment is shown in Figure 2. Similarly, the emergence and the shoot fresh weight of goosegrass seedlings were reduced as the rate of imazethapyr was increased, with the seedling growth being more sensitive to the herbicide as compared to the seedling emergence. Imazethapyr at a rate of 60 g a.i. ha⁻¹ was able to provide 100% inhibition of goosegrass emergence where this rate is 4-fold lower than the recommended rate. On the other hand, the ED₅₀ values for goosegrass emergence and shoot fresh weight were 12 and 3 g a.i. ha⁻¹ of imazethapyr, respectively. ED₅₀ values for goosegrass emergence were higher than



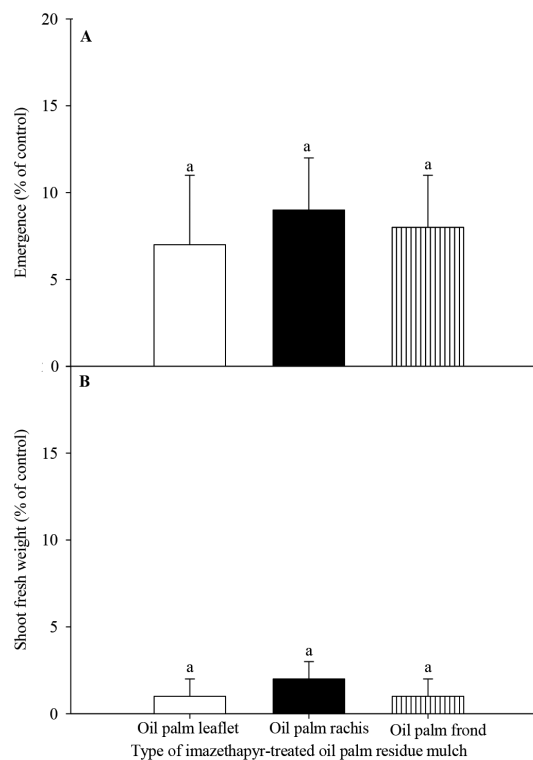
Vertical bars represent \pm standard deviation of mean

FIGURE 2. Effects of pre-emergence application of imazethapyr alone on emergence (A) and shoot fresh weight (B) of goosegrass in Kangkong series soil

ED₅₀ values for goosegrass shoot fresh weight when subjected to oil palm residues or imazethapyr (Figures 1 & 2). These higher ED₅₀ values were selected for mixture in the subsequent experiment since the pre-emergence herbicidal activity of imazethapyr or the crop residues can be reduced by environmental factors like soil moisture, rainfall, relative humidity, temperature and light under field conditions.

COMBINATION EFFECTS OF IMAZETHAPYR-TREATED OIL PALM RESIDUE MULCHES

Figure 3 shows the phytotoxicity of oil palm residue mulches at their respective ED₅₀ rates in combination with imazethapyr at a rate of 12 g a.i. ha⁻¹, respectively. It was noted that both goosegrass growth and emergence reduction were more than 90% when applied with any type of imazethapyr-treated oil palm residue mulches. In single application treatment, 43-50 g a.i. ha⁻¹ of imazethapyr was required to give 91-93% (ED₉₁₋₉₃) inhibition of goosegrass emergence. Interestingly, these



Vertical bars represent standard deviation (SD) of the mean. Means followed by similar letters have no significant differences after analyzed by Tukey test at 5% of significance level

FIGURE 3. Phytotoxic activity of imazethapyr-treated oil palm residue mulch on emergence (a) and shoot fresh weight (b) of goosegrass, one month after pre-emergence application

herbicide rates were reduced by 72-76% to exhibit the same inhibition effect in imazethapyr-treated oil palm residue mulch treatments (Table 2). Likewise, goosegrass shoot fresh weight was inhibited by 98-99% when treated with 50-57 g a.i. ha⁻¹ of imazethapyr (ED_{98.99}). Surprisingly, imazethapyr rate can be reduced by 76-79% when combined with oil palm residue mulch to perform the same ED_{98.99} inhibition effects (Table 3).

FIELD STUDY

Oil palm frond was selected as organic mulch in combination with imazethapyr even though oil palm rachis and leaflet provided comparable inhibitory effect on goosegrass emergence and growth. This is because oil palm frond residues are more abundant, easy to process and available as compared to other residues of oil palm. Naturally occurring weed community found in the experimental plots consisted of 17 weed species, including 11 broadleaves (65%), 4 grasses (24%) and 2 sedges (11%) weeds. These weed species are *Melothria affinis*, *Passiflora foetida*, *Euphorbia heterophylla*, *Mikania micrantha*, *Ageratum conyzoides*, *Mimosa diplotricha*, *Cleome rutidosperma*, *Croton hirtus*, *Asystasia gangetica*, *Phyllanthus amarus*, *Chromolaena odorata*, *Panicum* sp., *Echinochloa colona*, *Ischaemum muticum*, *Eleusine indica*,

TABLE 2. ED₉₁, ED₉₂ and ED₉₃ values of goosegrass in relation to pre-emergence applications of oil palm mulches or imazethapyr alone and imazethapyr-treated oil palm residue mulch in Kangkong series soil^a

Single application of oil palm residue or imazethapyr		Imazethapyr-treated mulch	
Oil palm rachis	Imazethapyr	Oil palm rachis	Imazethapyr
-----ED ₉₁ for emergence (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
^{-b}	43.1	1.7	11.9
Oil palm frond	Imazethapyr	Oil palm frond	Imazethapyr
-----ED ₉₂ for emergence (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
^{-b}	46.2	1.8	11.9
Oil palm leaflet	Imazethapyr	Oil palm leaflet	Imazethapyr
-----ED ₉₃ for emergence (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
2.7	50.2	1.4	11.9

^aED₉₁, ED₉₂ and ED₉₃ are the rates of oil palm residue mulch/imazethapyr alone or imazethapyr-treated oil palm residue mulch which cause 91, 92 and 93 % inhibition of emergence of goosegrass, respectively. ^bCannot be determined because the residues provided less than 90% inhibition of goosegrass emergence. ^cOil palm residue rate is expressed as t ha⁻¹ while imazethapyr rate is expressed as g a.i. ha⁻¹

TABLE 3. ED₉₈ and ED₉₉ values of goosegrass in relation to pre-emergence applications of oil palm mulches or imazethapyr alone and imazethapyr treated oil palm residue mulch in Kangkong series soil^a

Single application of oil palm residue or imazethapyr		Imazethapyr-treated mulch	
Oil palm rachis	Imazethapyr	Oil palm rachis	Imazethapyr
-----ED ₉₈ for shoot fresh weight (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
2.73	50.4	1.6	11.9
Oil palm leaflet	Imazethapyr	Oil palm leaflet	Imazethapyr
-----ED ₉₉ for shoot fresh weight (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
2.75	57.4	0.8	11.9
Oil palm frond	Imazethapyr	Oil palm frond	Imazethapyr
-----ED ₉₉ for shoot fresh weight (t ha ⁻¹ or g a.i. ha ⁻¹) ^c -----			
^{-b}	57.4	1.3	11.9

^aED₉₈ and ED₉₉ are the rates of oil palm residue mulch/imazethapyr alone or imazethapyr-treated oil palm residue mulch which cause 98 and 99% inhibition of shoot fresh weight of goosegrass, respectively. ^bCannot be determined because these residue only provided 80-86% inhibition of goosegrass shoot growth. ^cOil palm residue rate is expressed as t ha⁻¹, while imazethapyr rate is expressed as g a.i. ha⁻¹

Fimbristylis milicea and *Cyperus iria*. However, only five major species, namely *A. gangetica*, *E. colona*, *Panicum* sp., *M. micrantha* and *P. amarus* were selected to evaluate the effectiveness of different weed management strategies under the canopy areas of coconut trees.

It was noted that density of each weed species was not affected by any weed management strategies (Table 4). However, total weed density varied with the weed management strategy. Surprisingly, plots subjected to hand weeding alone had approximately 43% total weed density higher than that of untreated control plots. Likewise, hand weeding followed by application of oil palm frond mulch alone did not significantly help to reduce the total weed density. Interestingly, hand weeding followed by imazethapyr-treated mulch at a high rate reduced total weed density by 40% although no significant difference was observed in total weed density between this treatment

and untreated plots. The growth of each weed species responded differently when being subjected to different weed management strategies. Hand weeding alone was only able to reduce dry weight of a single weed species of *E. colona* by 57% as compared to that of untreated plots. In contrast, this treatment failed to reduce dry weight of *Panicum* sp. but, it is interesting to note that pre-emergence application of oil palm frond mulch after hand weeding was effective to reduce dry weight of *Panicum* sp. drastically by more than 70%.

Hand weeding followed by imazethapyr-treated mulch at a high rate provided excellent control of all weed species (Table 5). This treatment reduced dry weight of *A. gangetica*, *E. colona*, *Panicum* sp., *M. micrantha* and *P. amarus* by 94-99%. Moreover, this treatment managed to reduce total weed biomass by 95%. In comparison, hand weeding followed by imazethapyr-treated mulch at

TABLE 4. Effectiveness of different weed management strategies on weed density reduction in the coconut plantations three months after treatment

Weed control treatment	Weed density *					Total
	<i>Asystasia gangetica</i>	<i>Echinochloa colona</i>	<i>Panicum</i> sp.	<i>Mikania micrantha</i>	<i>Phyllanthus amarus</i>	
	----- no m ⁻² -----					
HW + HTM	23.2 a	5.8 a	9.8 a	10.4 a	7.0 a	58.2 a
HW + HTM×2	5.5 a	7.3 a	3.6 a	2.8 a	4.4 a	23.6 a
HW + OM	19 a	29.7 a	5.8 a	15 a	9.3 a	78.8 a
HW	12.8 a	20.8 a	18.3 a	7.0 a	12.4 a	71.4 a
SLSH + PE Glyphosate	12.2 a	8.0 a	6.3 a	7.2 a	12.3 a	45.9 a
SLSH	18.2 a	8.8 a	6.5 a	3.8 a	6.4 a	43.7 a
PE Glyphosate	7.0 a	18.8 a	15.8 a	8.0 a	14.2 a	63.8 a
Weedy (nontreated)	8.2 a	9.7 a	9.0 a	8.4 a	5.4 a	40.6 a

HW fb HTM, hand weeding followed by pre-emergence application of imazethapyr-treated mulch at a low rate (1.7 t ha⁻¹ oil palm frond + 12 g a.i. ha⁻¹ imazethapyr); HW fb HTM×2, hand weeding followed by pre-emergence application of imazethapyr-treated mulch at a high rate (3.4 t ha⁻¹ frond oil palm + 24 g a.i. ha⁻¹ imazethapyr); HW fb OM, hand weeding followed by pre-emergence application of oil palm frond mulch at 4 t ha⁻¹; HW, hand weeding alone; SLSH fb PE Glyphosate, slashing followed by post-emergence application of glyphosate at 1.83 kg a.i. ha⁻¹; SLSH, slashing alone; PE Glyphosate, post emergence application of glyphosate at 1.83 kg a.i. ha⁻¹ alone. *Mean with the same letter within a column are not different at $p = 0.05$

TABLE 5. Effectiveness of different weed management strategies on weed dry weight reduction in the coconut plantations three months after treatment

Weed control treatment	Weed dry weight *					Total
	<i>Asystasia gangetica</i>	<i>Echinochloa colona</i>	<i>Panicum</i> sp.	<i>Mikania micrantha</i>	<i>Phyllanthus amarus</i>	
	----- g m ⁻² (% of reduction) -----					
HW + HTM	17.4 b	11.8 c	40.2 c	14.3 ab	3.3 ab	87 ab
HW+ HTM×2	3.1 c	6.4 c	5.6 c	0.2 c	0.5 b	16 a
HW + OM	36.6 ab	65.7 a	40.2 c	15.9 ab	5.8 ab	164 ab
HW	62.0 a	45.8 b	142.8 ab	18.2 ab	5.9 ab	275 ab
SLSH+PE Glyphosate	38.7 ab	42.2 b	53.1 bc	11.9 ab	12.6 ab	159 ab
SLSH	64.4 a	48.4 b	34.2 c	4.6 bc	17.7 a	169 ab
PE Glyphosate	25.8 b	53.3 b	141.6 ab	9.9 abc	15.8 a	247 ab
Weedy (nontreated)	56.0 a	107.1 a	154.2 a	20.4 a	15.8 a	354 b

HW fb HTM, hand weeding followed by pre-emergence application of imazethapyr-treated mulch at a low rate (1.7 t ha⁻¹ oil palm frond + 12 g a.i. ha⁻¹ imazethapyr); HW fb HTM×2, hand weeding followed by pre-emergence application of imazethapyr-treated mulch at a high rate (3.4 t ha⁻¹ frond oil palm + 24 g a.i. ha⁻¹ imazethapyr); HW fb OM, hand weeding followed by pre-emergence application of oil palm frond mulch at 4 t ha⁻¹; HW, hand weeding alone; SLSH fb PE Glyphosate, slashing followed by post-emergence application of glyphosate at 1.83 kg a.i. ha⁻¹; SLSH, slashing alone; PE Glyphosate, post emergence application of glyphosate at 1.83 kg a.i. ha⁻¹ alone. *Mean with the same letter within a column are not different at $p = 0.05$

a low rate reduced dry weight of all weed species, except *M. micrantha* and *P. amarus*. Dry weight reduction of *A. gangetica*, *E. colona*, *Panicum* sp. and the total weed dry weight ranged from 70 to 90% when being subjected to this treatment.

DISCUSSION

The rates required for 50% reduction (ED₅₀) of the goosegrass seedling emergence ranged from 1.4 to 1.8 t ha⁻¹ for OPL, OPR and OPF mulches (Figure 1). It has been reported by Chauhan and Abugho (2013a) that rice straw residues at a rate of 3 t ha⁻¹ inhibited the goosegrass seedling emergence by 46%. This finding implies that the oil palm residue mulches are more phytotoxic to goosegrass than the straw residues of rice plants. Similarly, previous study demonstrated that mulches from oil palm residues

exhibited more phytotoxicity against shoot emergence and seedling growth of goosegrass when compared to those observed in rice, coconut and pineapple residues (Dilipkumar et al. 2015). In the present study, the reduction of goosegrass seedling emergence and growth by the oil palm residue mulches is rate-dependent (Figure 1), suggesting that the inhibition is most likely due to physical barrier or/and allelopathic effect of the residue mulches (Chuah & Lim 2015). The physical barrier help in reducing light penetration and decreased soil temperature fluctuation, thereby resulting in inhibition of weed germination (Kruidhoff et al. 2009; Liebman & Mohler 2001). Belz (2007) reported that crop allelopathy is an important component of weed interference that can control weeds through the release of allelochemical. Kruidhoff et al. (2009) documented that residues of winter rye (*Secale cereal* L.) and winter oilseed rape (*Brassica*

napus L.) consisted of allelochemicals such as indole glucosinolate, aliphatic glucosinolates glucobrassicin and 4-methoxyglucobrassicin which provided suppression of *Chenopodium album* L. and *Stellaria media* L.

It is clearly shown that ED_{50} values for emergence of goosegrass treated with imazethapyr or oil palm mulches alone are lower than ED_{50} values for growth of goosegrass subjected to the herbicide or the residues alone. These results implied that both imazethapyr and the oil palm residues are strong shoot inhibitors. Qian et al. (2009) reported that imazethapyr at 0.5 mg L^{-1} inhibited shoot growth of rice seedling by 27-75% depending on enantiomer types. Kundu (2011) also found that application of imazethapyr at $100 \text{ g a.i. ha}^{-1}$ significantly reduced growth of *Echinochloa colona* and *Echinochloa crus-galli* by 75-85% and 60-80%, respectively, at 45 days after spray. According to Vencill (2002), imazethapyr inhibited the growth of weeds a few hours after application, but injury symptoms usually appear after 1 to 2 weeks or more. Meristematic areas become chlorotic, followed by a slow general foliar chlorosis and necrosis (Vencill 2002). In addition, this herbicide damages nitrogen metabolism and indicates a regulatory effect on nitrogen uptake and translocation that would be mediated by the increase in free amino acid pool provoked by the inhibition of branched-chain amino acid biosynthesis (Zabalza et al. 2006). On the other hand, no information is available on the mode of action of oil palm residue mulch for weed suppression. Further research should be carried to determine allelochemicals involved in the phytotoxic activity of weed inhibition; as such the target site of the oil palm residues will be shown.

Abundant studies have been conducted to determine the phytotoxic activity of herbicide in combination with crop residue mulch on weed. These previous researches showed mixed results, from no interaction (Chauhan & Abugho 2013b; Mathers & Case 2010), antagonism (Chauhan & Abugho 2012; Teasdale et al. 2003) or synergism (Mathers & Case 2010; Teasdale et al. 2005) depending on the type and rate of herbicides and crop residues used. For instance, Chauhan and Abugho (2013b) reported that application of oxadiazon at $0.5 \text{ kg a.i. ha}^{-1}$, followed by fenoxaprop plus ethoxysulfuron at $0.45 \text{ kg a.i. ha}^{-1}$ treated rice straw mulch at 2 or 4 t ha^{-1} reduced total weed biomass by 93-98% as compared with untreated plots. However, the difference in weed biomass was statistically similar whether herbicide was used alone or combined with mulch. In other words, addition of the crop residue does not increase the phytotoxicity of the herbicides. On the other hand, it is found that the formulated herbicide of acetochlor and alachlor at 2.8 and $4.26 \text{ kg a.i. ha}^{-1}$, respectively, showed commercially acceptable weed control. However, the herbicides in combination with residue mulches of Douglas fir or pine provided mixed results; either commercially acceptable or lower weed control (Mathers & Case 2010). According to Chauhan and Abugho (2012), oxadiazon application in the presence of rice residue resulted in lower weed control than in the absence of residue. They suggested that some weed

species could have escaped the application of the herbicide where residue can bind soil-applied herbicide and result in lower efficacy.

In contrast, the present study has shown that all types of imazethapyr-treated oil palm residue mulches inhibited seedling emergence and growth of goosegrass by more than 90%. Oil palm residues is compatible with imazethapyr after being combined, as the herbicide rate can be reduced by 70-80% regardless of any parts of oil palm frond used (Figure 3). This result is in line with the finding of Teasdale et al. (2005), where the incorporation of S-metolachlor at $10 \text{ g a.i. ha}^{-1}$ and hairy vetch (*Vicia villosa*) residue at 5 t ha^{-1} gave synergistic interaction by inhibiting smooth pigweed emergence by 86%, compared with single S-metolachlor at $1000 \text{ g a.i. ha}^{-1}$ to achieve the same inhibitory effect. On the other hand, Mathers and Case (2010) demonstrated that a single application of acetolachlor at $2.8 \text{ kg a.i. ha}^{-1}$ or hardwood gave 46% and 0% weed control, respectively. Interestingly, acetolachlor-treated hardwood provided 100% weed control at 110 days after treatment.

It has been documented that plant lignin can be used for the controlled liberation of herbicides such as metribuzine, alachlor, carbofuran, cloroambeno (Cotterill & Wilkins 1996; Wilkins 1990; Zhao & Wilkins 2000), diuron and 2, 4 D (Oliveira et al. 2000). According to Khalid et al. (2000), the lignin contents of OPL, OPR and OPF ranged from 20-30%. It is likely that imazethapyr-treated oil palm residue mulches work like granules; they work as herbicide carriers. In addition, this property possibly makes oil palm residue as a good candidate for slow release carrier of imazethapyr with water solubility of 1400 g L^{-1} and low K_{oc} value of 11-31 mL g^{-1} (Anonymous 2007), thereby decreasing the leaching potential of imazethapyr in the soil. Knight et al. (2001) reported that pine bark, pine straw and newspaper mulches significantly reduced leaching of pendimethalin, isoxaben and metolachlor by 35-74% as compared to the bare soil herbicide application. Tharayil et al. (2006) claimed that competition for sorption sites arises if the same sites can be occupied by more than one non-identical molecule. Allelochemicals released by oil palm residues powders and imazethapyr may be competing for the same sites in the soil. As a result, more imazethapyr molecules are available for uptake by goosegrass seedlings as reported by Dilipkumar et al. (2012) who studied the effects of soil types on phytotoxicity of pretilachlor in combination with sunflower leaf extracts on barnyardgrass. Alternatively, synergistic effects may have occurred between imazethapyr and allelochemicals of OPF, thus causing great inhibition of goosegrass seedlings.

Weed species in field experiment were selected based on the presence of dense infestations under the canopy areas of coconut trees (Tables 4 and 5). Since density of *E. indica* was relatively lower as compared to other weed species, it was not included when assessed the effectiveness of weed management strategy in the canopy areas. A total of eight different treatments were included as a weed management strategy in the canopy areas of coconut trees based on several reasons. Slashing either

by hand or tractors harrowing, applications of glyphosate as post emergence herbicide and/or in combination are common practices for weed management in coconut plantations (Senarathne & Perera 2011). These weed management strategies were included in the present study as a comparison with the novel weed management strategy introduced in this study. Although imazethapyr-treated oil palm frond at 12 g a.i. ha⁻¹ plus 1.8 t ha⁻¹, shows promising results when applied as mulch for weed control under glasshouse conditions, these results cannot be directly extrapolated to the field conditions as the efficacy of this treatment are influenced by abiotic factors such as soil moisture, rainfall, relative humidity, soil temperature, light (Brown 2001; Riethmuller-Haage et al. 2007; Stewart et al. 2010) and biotic factor like weed species and soil microbes (Gower et al. 2002; Loux et al. 2008; Stewart et al. 2010). Hence, the application rate was increased twice besides examining imazethapyr-treated oil palm frond mulch at 12 g a.i. ha⁻¹ plus 1.8 t ha⁻¹ in the fields. Nevertheless, this rate is still 90% lower than the recommended rate of imazethapyr. It is well known that reduced rate of herbicide could speed up the occurrence of herbicide resistance when it is used as single application. Imazethapyr-treated OPF provided excellent weed control in the field probably due to the occurrence of synergistic interaction between imazethapyr and allelochemicals of OPF. Thus, this may reduce development rate of weed resistance to imazethapyr.

Comparison among eight weed management treatments in the field study revealed that imazethapyr-treated mulch at 24 g a.i. ha⁻¹ plus 3.4 t ha⁻¹ provided excellent control of weed (Tables 4 and 5). The application of imazethapyr-treated mulch at 12 g a.i. ha⁻¹ plus 1.7 t ha⁻¹ after hand weeding showed excellent results under glasshouse conditions. However, this treatment did not provide adequate weed control under field conditions. Likewise, Stougaard et al. (1990) reported that although injury was apparent with the application of imazethapyr in the glasshouse bioassay, the effect of injury was minimal in the field bioassay. This variation response is largely due to the differences in soil moisture conditions which affect the availability of imazethapyr (Stougaard et al. 1990) and alteration in herbicide concentration (Moyer 1987). Herbicide concentration in soil inversely related to the sum of soil moisture content and soil water partition coefficient (Green & Obien 1969). Zhang et al. (2001) have demonstrated that higher soil moisture at 50% can reduce the efficacy of imazethapyr when applied as pre-plant treatment. In this study, the treatments were applied during rainy season. As a result, soil moisture under field conditions is likely higher than that under glasshouse conditions, thus reducing the efficacy of imazethapyr on weeds.

Surprisingly, application of oil palm residues at 4 t ha⁻¹ after hand weeding treatment did not improve weed control and contradicted with the findings in the glasshouse bioassay. The lower level of weed control provided by

the oil palm frond residues under field conditions may be attributed to early heavy rainfall in the field plots which might have washed away some of the oil palm frond residues from the canopy areas of coconut plantations (Somireddy 2012) while the oil palm frond residues remain intact in the cups under glasshouse conditions. Efficacy of oil palm residues for weed control may be affected when the thickness of mulch is reduced or not homogenous due to heavy rainfall. In contrast, efficacy of imazethapyr-treated mulch was less affected by heavy rainfall because the mulches contained imazethapyr which still can inhibit weed emergence and growth although the thickness of mulch may be reduced after heavy rainfall.

In this study, plots subjected to single hand weeding had higher weed infestation and did not affect weed biomass except *Echinochloa colona* (Tables 4 and 5). In comparison, Aslam et al. (2007) reported that twice-hand weeding treatment gave excellent weed control where weed density and weed biomass were reduced by 85% and 98%, respectively, in chickpea fields. Similarly, twice-hand weeding also significantly reduced weed density of *Echinochloa crus-galli* (barnyardgrass), *Digera arvensis* Forsk. (False amaranth), *Dactyloctenium aegyptium* (L.) Willd., (Crowfoot grass), *Euphorbia prostrata* Aiton. (Prostrate sandmat) and *Convolvulus arvensis* L. (Field bindweed) by at least 78% as compared with weedy check in maize fields (Saeed et al. 2013).

In the present study, slashing alone significantly reduced dry weight of *E. colona*, *Panicum* sp. and *M. micrantha* (Table 5). The effectiveness of slashing is dependent on several factors such as the timing of slashing (Shelton 2012), height and frequency of slashing (Henry et al. 2007; Summerlin et al. 2000). Senerathne and Perera (2011) reported that slashing caused more damage to dicotyledonous weeds and less damage to root systems and underground plant parts such as stolons, bulb and rhizomes of monocotyledonous weeds. Hence, they considered that dicotyledonous weeds are much easier to control by slashing (Senerathne & Perera 2011). Nevertheless, Butler et al. (2013) reported that a single slashing on large crabgrass (*Digitaria sanguinalis* (L.) Scop., barnyardgrass (*E. crus-galli*), giant ragweed (*Ambrosia trifida* L.) and common lambsquarters (*Chenopodium album* L.) failed to kill these weeds but repeated slashing reduced total weed dry weight to below 40% for all species as compared with non-slashing plants.

CONCLUSION

Imazethapyr at 12 g a.i. ha⁻¹ in combination with oil palm residues of leaflet, rachis or frond at rates of 1.4-1.8 t ha⁻¹ inhibited *Eleusine indica* emergence and growth by 90-100% under glasshouse conditions. Field experiment in coconut plantation further revealed that imazethapyr-treated oil palm frond mulch at a rate of 24 g ai ha⁻¹ + 3.4 t ha⁻¹ provided excellent control of *Mikania micrantha*, *Asystasia gangetica*, *Phyllanthus amarus*, *Panicum* sp., and

Echinochloa colona. These findings implied that oil palm frond residue was not only compatible with imazethapyr, but also has the potential to reduce recommended rate of imazethapyr by 90% without comprising excellent weed control.

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REFERENCES

- Anonymous. 2007. *Extension Toxicology Network; Imazethapyr*. <http://pmep.cce.cornell.edu/profiles/extoxnet/haloxyp-methylparathion/imazethapyr-ext.html>. Accessed on August 15, 2014.
- Aslam, M., Ahmad, H.K., Ahmad, E., Khan, M.A. & Sagoo, A.G. 2007. Effect of sowing methods and weed control techniques on yield and yield components of chickpea. *Pakistan Journal of Weed Sciences Research* 13(1/2): 49-61.
- Belz, R.G. 2007. Allelopathy in crop/weed interactions-an update. *Pest Management Science* 63(4): 308-326.
- Brown, K. 2001. *Environmental impact on herbicide performance*. www.umanitoba.ca/faculties/afs/MAC_proceedings/2001/pdf/brown.pdf. Accessed on November 30, 2014.
- Butler, R.A., Brouder, S.M., Johnson, W.G. & Gibson, K.D. 2013. Response of four summer annual weed species to mowing frequency and height. *Weed Technology* 27(4): 798-802.
- Case, L.T. & Mathers, H.M. 2006. Herbicide-treated mulches for weed control in nursery container crops. *Journal of Environment and Horticulture* 24(2): 84-90.
- Chauhan, B.S. & Abugho, S.B. 2013a. Effect of crop residue on seedling emergence and growth of selected weed species in a sprinkler-irrigated zero-till dry-seeded rice system. *Weed Science* 61(3): 403-409.
- Chauhan, B.S. & Abugho, S.B. 2013b. Integrated use of herbicide and crop mulch in suppressing weed growth in a dry-seeded rice system. *American Journal of Plant Science* 4: 1611-1616.
- Chauhan, B.S. & Abugho, S.B. 2012. Interaction of rice residue and PRE herbicides on emergence and biomass of four weed species. *Weed Technology* 26(4): 627-632.
- Chuah, T.S. & Lim, W.K. 2015. Assessment of phytotoxic potential of oil palm leaflet, rachis and frond extracts and powders on goosegrass (*Eleusine indica* (L.) Gaertn.) germination, emergence and seedling growth. *Malaysian Applied Biology* 44(2): 75-84.
- Cotterill, J.V. & Wilkins, R.M. 1996. Controlled release of phenylurea herbicides from a lignin matrix: Release kinetics and modification with urea. *Journal of Agricultural and Food Chemistry* 44(9): 2908-2912.
- Dilipkumar, M., Mazira, C.M. & Chuah, T.S. 2017. Evaluation of sequential application of slashing and glyphosate for drought grass (*Ischaemum muticum* L.) control in coconut plantation. *The Journal of Animal & Plant Sciences* 27(1): 200-206.
- Dilipkumar, M., Mazira, C.M. & Chuah, T.S. 2015. Phytotoxicity of different organic mulches on emergence and seedling growth of goosegrass (*Eleusine indica*). *Journal of Tropical Agriculture and Food Science* 43(2): 145-153.
- Dilipkumar, M., Adzemi, M.A. & Chuah, T.S. 2012. Effects of soil types on phytotoxic activity of pretilachlor in combination with sunflower leaf extracts on barnyardgrass (*Echinochloa crus-galli*). *Weed Science* 60(1): 126-132.
- DOA. 2015. Industrial crops statistics (in Malay language). Putrajaya, Malaysia: Malaysian Department of Agriculture. p. 9.
- DOA. 2007. Coconut production package (in Malay language). Putrajaya, Malaysia: Malaysian Department of Agriculture. p. 36.
- Gower, S.A., Loux, M.M., Cardina, J. & Harrison, S.K. 2002. Effect of planting date, residual herbicide, and post emergence application timing on weed control and grain yield in glyphosate-tolerant corn (*Zea mays*). *Weed Technology* 16(3): 488-494.
- Green, R.E. & Obien, S.R. 1969. Herbicide equilibrium in soils in relation to soil water content. *Weed Science* 17(4): 514-519.
- Gunathilake, H.A.J. 1993. An appraisal of coconut grower's reaction and observation on coconut research institute recommended cultural practices and other related issues. *CRI Report v. 2*. pp. 89-96.
- Hairuddin, M.A., Tengku Mohd Arif, T.A., Sivapragasm, A. & Asrulidin, A.S. 2010. Situation and outlook of the coconut industry in Malaysia. In *Proceedings National Coconut Conference: Opportunities for a Sunrise Industry; 2009*. Perak, Malaysia: Malaysian Agricultural Research and Development Institute (MARDI). pp. 109-111.
- Henry, G.M., Burton, M.G. & Yelverton, F.H. 2007. Effect of mowing on lateral spread and rhizome growth of troublesome Paspalum species. *Weed Science* 55(5): 486-490.
- ISTA. 1993. *Hand Book for Seeding Evaluation*. Zurich, Switzerland: International Seed Testing Association (ISTA).
- Iyagba, A.G., Isirima, C.B. & Akonye, L. 2012. Influence of rumen-base organic mulch treatment on weed control and maize performance in rivers state, Nigeria. *ARPJ Journal of Agricultural and Biological Science* 7: 524-526.
- Jodaugiene, D., Pupaliene, R., Urboniene, M., Pranckietis, V. & Pranckietiene, I. 2006. The impact of different types of organic mulches on weed emergence. *Agronomy Research* 4: 197-201.
- Khalid, H., Zin, Z.Z. & Anderson, J.M. 1999. Effect of oil palm residues management at replanting on soil nutrient dynamics and oil palm growth. In *Proceeding of the PORIM International Palm Oil Congress*. Kuala Lumpur, Malaysia: Malaysian Palm Oil Board. pp. 235-246.
- Khalid, H., Zin, Z.Z. & Anderson, J.M. 2000. Decomposition process and nutrient release pattern of oil palm residue. *Journal of Oil Palm Research* 12: 46-63.
- Knight, P.R., Gilliam, C.H., File, S.L. & Reynolds, D. 2001. Mulches reduce herbicide loss in the landscape. *Proceeding of Southern Nursery Assistance Research Conference* 46: 461-463.
- Kruidhoff, H.M., Bastiaans, L. & Kropff, M.J. 2009. Cover crop residue management for optimizing weed control. *Plant and Soil* 318(1-2): 169-184.
- Kuk, Y.N., Kwon, O.D., Jung, H., Burgos, N.R. & Jaock, G. 2002. Cross-resistance pattern and alternative herbicides for *Rotala indica* resistant to imazosulfuron in Korea. *Pesticide Biochemistry and Physiology* 74(3): 129-138.
- Kundu, R. 2011. Bioefficacy of imazethapyr on the predominant weeds in soybean. *Journal of Crop and Weed* 7(2): 173-178.
- Liebman, M. & Mohler, C.L. 2001. Weed and soil environment. In *Ecological Management of Agricultural Weeds*, edited by Liebman, M., Mohler, C.L. & Staver, C.P. Cambridge, UK: Cambridge University Press. pp. 210-268.

- Liyanage, L.V.K. & De Liyanage, M.S. 1989. Weed control understorey weed management in coconut lands. *CORD* 1: 48-56.
- Loux, M.M., Dobbels, A.F., Johnson, W.G., Nice, G.R.W., Bauman, T.T. & Stachler, J.M. 2008. *Weed Control Guide for Ohio and Indiana*. Extension Bulletin 789/Purdue Extension Pub. No. WS16. Columbus, Ohio: Ohio State University. p. 201.
- Mathers, H.M. 2003. Novel methods of weed control in containers. *HortTechnology* 13(1): 28-31.
- Mathers, H.M. & Case, L.T. 2010. Microencapsulated herbicide-treated bark mulches for nursery container weed control. *Weed Technology* 24(4): 529-537.
- Moraidi, A., Teh, C.B.S., Goh, K.J., Husn, A.M.H. & Fauziah, I. 2012. Evaluation of four soil conservation practices in a non-terraced oil palm plantation. *Agronomy Journal* 104: 1727-1740.
- Moyer, J.R. 1987. Effect of soil moisture on the efficacy and selectivity of soil applied herbicides. *Review of Weed Science* 3: 119-134.
- Oliveira, S.C., Pereira, F.M., Ferraz, A., Silva, F.T. & Goncalves, A.R. 2000. Mathematical modeling of controlled-release systems of herbicides using lignins as matrices. *Applied Biochemistry and Biotechnology* 84(1): 595-615.
- Qian, H., Hu, H., Mao, Y., Ma, J., Zhang, A., Liu, W. & Fu, Z. 2009. Enantioselective phytotoxicity of the herbicide imazethapyr in rice. *Chemosphere* 76(7): 885-892.
- Riethmuller-Haage, I., Bastiaans, L., Kempenaar, C., Smutny, V. & Kropff, M.J. 2007. Are pre-spraying growing conditions a major determinant of herbicide efficacy? *Weed Research* 47(5): 415-424.
- Saeed, M., Haroon, M., Waqas, M., Fahad, S., Ali, S. & Bibi, H. 2013. Mulching: A management practice for weeds in maize. *Pakistan Journal of Weed Sciences Research* 19(4): 403-410.
- Samarajeewa, A.D., Senaratna, R.P.B.S.H.S. & Perera, K.C.P. 2004. Effect of different control methods of *Imperata cylindrica* on coconut (*Cocos nucifera*) yield in low country dry zone of Sri Lanka. *COCOS* 16: 37-42.
- Senarathne, S.H.S. & Perera, K.C.P. 2011. Effect of several weed control methods in tropical coconut plantation on weed abundance, coconut yield and economical value. *International Research Journal of Plant Science* 2(2): 25-31.
- Senarathne, S.H.S., Samarajeewa, A.D. & Perera, K.C.P. 2003. Comparison of different weed management systems and their effects on yield of coconut plantations in Sri Lanka. *Weed Biology and Management* 3(3): 158-161.
- Shelton, A.L. 2012. Mowing any time after midsummer can manage Japanese stilt grass. *Invasive Plant Science and Management* 5(2): 209-216.
- Singh, H.P., Batish, D.R. & Kohli, R.K. 2006. *Handbook of Sustainable Weed Management*. New York: Haworth Press. p. 892.
- Somireddy, U.R. 2012. Effect of herbicide-organic mulch combinations on weed control and herbicide persistence, Ph.D dissertation. United States: the Ohio State University (Unpublished).
- Stewart, C.L., Nurse, R.E., Hamill, A.S. & Sikkema, P.H. 2010. Environment and soil conditions influence pre-and post-emergence herbicide efficacy in soybean. *Weed Technology* 24(3): 234-243.
- Stougaard, R.N., Shea, P.J. & Martin, A.R. 1990. Effect of soil type and pH on adsorption, mobility, and efficacy of imazaquin and imazethapyr. *Weed Science* 38: 67-73.
- Summerlin, J.R. Jr., Coble, H.D. & Yelverton, F.H. 2000. Effect of mowing on perennial sedges. *Weed Science* 48(4): 501-507.
- Teasdale, J.R., Shelton, D.R., Sadeghi, A.M. & Isensee, A.R. 2003. Influence of hairy vetch residue on atrazine and metolachlor soil solution concentration and weed emergence. *Weed Science* 51(4): 628-634.
- Teasdale, J.R., Pillai, P. & Collins, R.T. 2005. Synergism between cover crop residue and herbicide activity on emergence and early growth of weeds. *Weed Science* 53(4): 521-527.
- Tharayil, N., Bhowmik, P.C. & Xing, B. 2006. Preferential sorption of phenolic phytotoxins to soil: Implications for altering the availability of allelochemicals. *Journal of Agricultural and Food Chemistry* 54(8): 3033-3040.
- Uwah, D.F. & Iwo, G.A. 2011. Effectiveness of organic mulch on the productivity of maize (*Zea Mays* L.) and weed growth. *The Journal of Animal and Plant Sciences* 21(3): 525-530.
- Vencill, W.K. 2002. *Herbicide Handbook*. 8th. ed. Champaign: Weed Science Society of America.
- Wilkins, R.M. 1990. *Controlled Delivery of Crop-Protection Agents*. United Kingdom: Taylor & Francis Ltd.
- Zabalza, A., Gaston, S., Ribas-Carbo, M., Orcaray, L., Igal, M. & Royuela, M. 2006. Nitrogen assimilation studies using ¹⁵N in soybean plants treated with imazethapyr, an inhibitor of branched-chain amino acid biosynthesis. *Journal of Agricultural and Food Chemistry* 54(23): 8818-8823.
- Zhang, W., Webster, E.P. & Selim, H.M. 2001. Effect of soil moisture on efficacy of imazethapyr in greenhouse. *Weed Technology* 15(2): 355-359.
- Zhao, J. & Wilkins, R.M. 2000. Controlled release of a herbicide from matrix granules based on solvent-fractionated organosolv lignins. *Journal of Agricultural and Food Chemistry* 48(8): 3651-3661.
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