Full Length Article

Effect of Cover Crops on Weed Suppression in Oil Palm Plantation

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Abstract

Weeds are a major problem in oil palm plantation and use of herbicides is a common way for weed control. Cover crops have the potential to control weeds in oil palm areas. Hence field experiments were designed over two years in an oil-palm plantation in Malaysia to compare the effect of cover crops on common local weed species. Six treatments include four ground covers *viz. Axonopus compressus, Calopogonium caeruleum + Centrosema pubescens, Mucuna bracteata* and *Pueraria javanica + C. pubescens*, and glufosinate-ammonium herbicide (weeded), and natural vegetation (un-weeded) were evaluated. *A. compressus, M. bracteata* and other legume cover crops achieved 100% coverage at 3, 6 and 9 months after planting, respectively. Cover crops and un-weeded treatments produced comparable vegetation biomass. *A. compressus* and *M. bracteata* produced higher total biomass (800 g m^{-2}) compared to the both mix of the conventional legume cover crops (600 g m^{-2}). The weed densities, in the un-weeded plots were 255, 544, 419, 445 and 502 plants m^{-2} at 9, 12, 15, 18 and 24 months after planting, with the corresponding biomasses of 254, 804, 395, 630 and 734 g m^{-2}, respectively. The decline in percentage weed dry weight and weed density due to the cover crop treatments in comparison to the un-weeded treatment ranged between 97.3 - 99.9% and 94.77 - 99.73%, respectively. High levels of phenolic compounds were observed from the *P. javanica + C. pubescens* treatment. The study suggests that cover crop management systems have potential to be include in sustainable oil palm plantation for reduce use of herbicides. The results also suggest that *A. compressus* could be considered as a suitable candidate as a cover crop under oil palm. © 2015 Friends Science Publishers

Keywords: Oil palm; Cover crop establishment; Weed biomass; Weed density; Phenolic compounds

Introduction

Palm oil is produced on large industrial plantations in Malaysia and Indonesia. Oil palm covered more than 12 million ha in the world in 2007, a 50% increase over the past 10 years, with Malaysia having 41% and Indonesia 44% of the total (MADI, 2009/2010). High yields in these countries account for well over 80% of both production and exports. Between 1990 and 2005 the area of oil palm in Malaysia increased by 1.8 million ha to 4.2 million ha, and in 2010 increased by 4.5% to 4.85 million hectares compared to 4.69 million hectares in 2009 (MPOB, 2012).

Oil palm yields in Malaysia are jeopardized by the presence of weeds. Yeow *et al*. (1982) suggested that in oil palm plantations, weeds can cause 6-20% losses in yield. According to Kustyanti and Horne (1991), the eradication of very dense stands of *Asystasia* (especially *A. gangetica*) in an oil palm plantation resulted in a 12% increase in fresh fruit bunch production. In general, in most planted areas the cost to control weeds in immature or mature oil palm is the second highest after fertilizer cost (Sahid and Chan, 2000; Azahari *et al.*, 2004).

Malaysia relies heavily on conventional methods to produce, increase and sustain food production. The use of herbicides to control weeds is a common practice and extensive in oil palm plantations in Malaysia (Chey, 2006; Corley and Tinker, 2003). Herbicides usage showed a 61.8% increase from 1998 until 2007 (MCCP, 2009). Use of chemicals in agriculture began to pick up from 2002. This increase was largely due to herbicides, which contributed about 71.6% of the total chemicals used in 2007 in comparison to 19.8% for insecticides, 5.4% for fungicides and 3.2% for rodenticides (MADI, 2009/2010). Herbicides can be a very effective and economical method of controlling weeds. However, the use of herbicides can affect human health ranging from skin rashes to death, cause acute toxicity and contaminate soil and water resources. In Malaysia, two main herbicides, Basta® (Glufosinate-ammonium) and Roundup® (Glyphosate), are widely used for effective control of weeds infesting oil palm plantations. Further, the prolonged and widespread use of these two herbicides in the oil palm growing regions increases the risk of herbicide resistance. The extent of weed resistance to glufosinate-ammonium in Malaysia has been reviewed by Adam *et al.* (2010). In addition replacement soft weeds such as *Paspalum conjugatum* and *A. compressus* by noxious

weeds, habitat destruction of predators of insect pests, eradication of beneficial insects and damage to oil palms are some of the disadvantages of the use of chemical methods.

Use of some form of organic weed control approaches in conventional agriculture is desirable to reduce the use of herbicides. The cultivation of leguminous cover crops under oil palm plantations in tropical Asia was initially developed in response to the high rates of runoff and soil erosion (Turner and Gillbanks, 2003), but maintaining cover crops provides additional benefits e.g. preserves the fertility and productivity of fragile resources particularly during the period between land clearing and full ground coverage by soft vegetation (Corley and Tinker, 2003; Goh and Chiu, 2007). Cover crops could also control weed species and influence weed communities in perennial crop systems (Gago *et al.*, 2007; Baumgartner *et al.*, 2008). The commonly used leguminous cover crops species in Malaysia are *Pueraria phaseloides* (synonym for *Pueraria javanica*), *Centrosema pubescens*, *Calopogonium mucunoides*, *C. caeruleum* and of late *Mucuna bracteata* (Mathews and Saw, 2007). In Malaysia, *A. compressus* is one of the soft grass species that is widely used as ground cover to protect soil erosion, as turf grass for landscaping and for sports fields as well as to conserve soil moisture (Jurami, 2003). However, data on the use of perennial cover crops including soft grasses such as *A. compressus* to control weeds in oil palm are still lacking. Samedani *et al.* (2012) showed that this soft grass is highly competitive against *A. gangetica* and is less susceptible to *Pennisetum polystachion* interference than the legumes cover crops. It was hypothesized that *A. gangetica*. as a cover crop in oil palm plantation would suppress weeds as it would establish soon and smother weeds. Hence, the present study was designed to compare the ability of conventional legume cover crops and *M. bracteata* with *A. compressus* to suppress weeds. Cover crops establishment, biomass and shoot and litter phenolic compounds and phenolic compounds in soil under them were also monitored to document the significant effects of the cover crops on such parameter.

Materials and Methods

Experimental Site

The experiment was conducted in an existing four-year old D × P oil-palm plantation at Field 15, Universiti Agriculture Park (UAP), Universiti Putra Malaysia (UPM) (3°02'N, 101°42'E; elevation 31 m asl), Selangor, Malaysia. The experiment was carried out in an area of about 0.6 ha during the period from September of 2010 to September of 2012. The soil was Serdang series (fine loamy kaolinitic, isohyperthermic, typic Palenduk) with pH=4.69, CEC= 6.4 cmol kg^{-1}, total N= 0.12%, available P= 4.1 ppm, exchangeable K= 31 ppm, exchangeable Ca= 68.3 ppm, exchangeable Mg= 49.3 ppm and organic carbon= 1.4%.

Land Preparation

The existing dried oil palm fronds were moved out of the field. The field was given a blanket spray to eradicate all green vegetation by using the herbicides Roundup (Glyphosate 600 g a.i. ha^{-1}) + Ally (Metsulfuron methyl 2.1 a.i. ha^{-1}). Then the soil in the inter-rows was ploughed to a depth of approximately 15cm and rotavated to prepare the seedbeds.

Experimental Layout

Each treatment plot covered an area of about 300 m^2 and contained eight palms. Only the central two palms of each plot were used for measurements. Each palm was planted at the planting distance of 9 m apart on an equilateral triangle pattern. Each plot size was 15.5 m × 18 m and included two palms in the center.

Experimental Design and Treatments

The six treatments were arranged in a randomized complete block design with three replications. The treatments were randomly assigned to the plots in each block. The six treatments were applied to the entire plot area, except the circle around the oil palms (about 1.5 m). The six treatments were: 1. Un-weeded (natural vegetation), 2. Weeded (sprayed with Glufosinate-ammonium), 3. Cover crop: *M. bracteata*, 4. Cover crop: *Axonopus compressus*, 5. Cover crop: *P. javanica* + *C. pubescens* (4:1) and 6. Cover crop: *C. caeruleum* + *C. pubescens* (1:1).

Application of Treatments

M. bracteata seed coats were clipped at the opposite side of the hilum to improve permeability of water and then treated with Benomyl at 0.2% (2 g L^{-1}) to avoid fungal contamination. Treated seeds were pre-germinated on filter paper for 3 days in the laboratory. Germinated seeds were inoculated with *Rhizobium* sp. at a rate of 50 g for every 5 kg of seeds to enhance nodulation. Inoculated seeds were planted singly at 1-2 cm depth into polybags of size 15 cm × 25 cm. Polybags were filled with 2 parts top soil + 1 part sand + a quantity organic matter, and 10 g of phosphate rock was added to each polybag. After shoot appearance, another round of fungicide treatment was given by drenching the germinated seeds with 0.2% Benomyl. Watering was carried out every day. Polybags were kept in the nursery for 12 weeks. *M. bracteata* seeds are very sensitive to excess water, especially from the rains. For better germination, polybags were kept in 50% shade for 2 weeks and after that they were exposed to direct sunlight. Only manual hand weeding was carried out in the nursery. The *M. bracteata* seedlings were pruned before transplanting into the field to encourage rapid growth. The pruned seedlings were transferred from nursery to the field by tractor. The planting holes were dug 20 cm × 20 cm by 25 cm (deep) and rock

phosphate was applied to each hole. *M. bracteata* was planted at an interrow and intrarow spacing of 1.5 m apart at a density of 680 seedling ha^{-1}.

Axonopus compressus sod sizes of 60 cm × 30 cm were planted with 60 cm distance between sods. The *A. compressus* was planted at a density of 5000 m^2 sod ha^{-1}. *C. pubescens*, *P. javanica* and *C. caeruleum* seed coats were scarified with sandpaper and inoculated with *Rhizobium* species. Three parallel drills, 2.1 m apart, were dug with a hoe in the inter and intra-row of palms. Scarified *P. javanica* and *C. pubescens* seeds (at a ratio of 4:1) were mixed and planted into the drills (at the rates of 12:3 kg ha^{-1}). *C. caeruleum* and *C. pubescens* seeds were mixed at a ratio of 1:1, and sown at the rate of 3:3 kg ha^{-1}. Seeds were broadcasted by hand and loose soil was then pressed back over the seeds. To facilitate the establishment of cover crops the oil palm trees were pruned as each tree had 25 fronds.

In the un-weeded plots, natural vegetation was allowed to colonize this treatment without any control to maximize weed–oil palm competition. The weeded plots, was maintained free of vegetation by spraying with Basta (glufosinate-ammonium at 500 g a.i. ha^{-1}) every three months, to minimize weed competition and maximize the potential growth of oil palm.

Fertilization

Essential fertilizers were applied to cover crops in all plots, at different times (Table 1). The fertilizer was applied to all oil palm plants in the experiment area every four months at a rate of 4 kg NPK Blue (12:12:17). All fertilizers were buried, in four pockets (10-15 cm deep) in line with the oil palm canopy.

Weeding

The cover crops were maintained weed-free using manual weeding in the first three months after planting. The circle weeded area around the oil palms (1.5 m diameter), were not planted with cover crops. This area was sprayed using Basta (Glufosinate-ammonium 500 g a.i. ha^{-1}) at six-week intervals to maintain weed-free and prevent legumes from creeping onto palms and smother them.

Parameters Measured

The date of cover crop establishment recorded unlit 100% covering. The biomass production of cover crops was measured at 9, 12, 15, 18, 21 and 24 months after planting within eight quadrates (each 0.25 cm^2) in each plot. The biomass and density of each weed species were measured at 9, 12, 15, 18, 21 and 24 months after the cover crops were planted. Samples were taken by randomly placing a 0.25 cm^2 quadrate at eight locations in each experimental plot. All above ground weed vegetation was harvested and

separated by weed species, dried in an oven at 75°C for 72 h and dry weights were recorded (Chew *et al.*, 1999). Weed density and weed dry weights were expressed as no m^{-2} and g m^{-2}, respectively. Irrigation, because of precipitation was not done. Temperature and precipitation data were obtained from the nearest Malaysia Irrigation Management Information System (CIMIS) weather station (Table 2). In the oil palm plantation was not observed any pest problem during these two years.

For the estimation of water-soluble phenolics, 5 g of plant tissue or soil samples were shaken with distilled water (50 mL) at room temperature in the dark for 18 h and then filtered through Whatmans No. 1 filter paper. The extracts were preserved in a refrigerator at 4°C (Rashid *et al.*, 2010). The amount of phenolics in the water extract was estimated using the Folin-Ciocalteu assay. For this assay, an aliquot of 1.0 mL of plant extract was placed into a test tube and 5 mL of 2% Na$_2$CO$_3$ in 0.1 N NaOH was added and mixed with a test-tube mixer. Five minutes later, 0.5 mL of Folin-Ciocalteu reagent was added, and the solution was mixed again. The absorbance was read using a spectrophotometer (Model UV-3101PC, UV-VIS NIR) at 760 nm after 2 h. A standard curve was prepared in a similar manner using a concentration series of gallic acid solutions in water and then the phenolic concentration in the plant extracts was estimated (as gallic acid equivalent), based on this standard curve. For the estimation of acetone extractable phenolics in the plant tissue or soil samples, the same protocol was used (except for the extraction). The extracts were prepared using 70% acetone.

Statistical Analysis

Analyses of variance (ANOVA) were performed to determine the effects of treatments and sampling dates on weed and cover-crop biomass. The data were subjected to repeated measure analysis of variance. Sampling date was considered a repeated measure. The PROC GLM in SAS 9.2 was used for the data analysis (SAS Institute Inc., 2004) and significant differences among treatment means were tested using Tukey's studentized range test at the 5% level of probability.
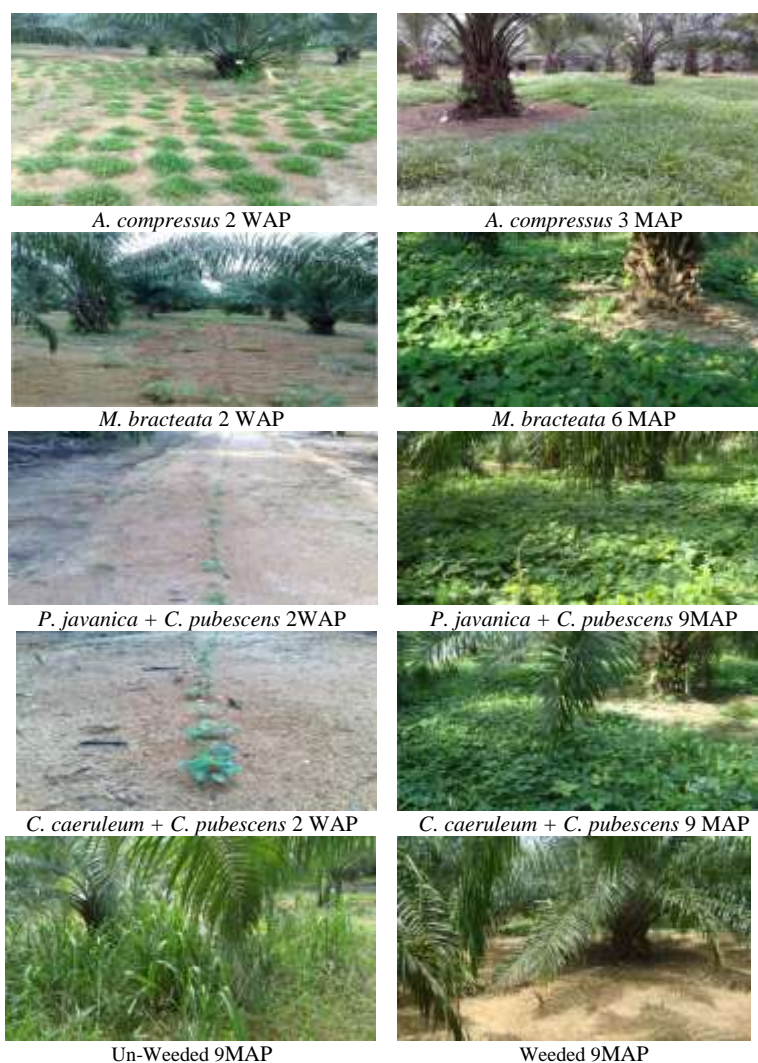
Results

Cover Crop Establishment

A. compressus grew well from the start of the experiment. The initial establishment of *M. bracteata* in the first two to three months was rather slow. The establishment of *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* was slower compared to *M. bracteata* seedlings. Fig. 1 show cover crop establishment and weed status in Un-Weeded and Weeded treatments at different times.

Table 1: Fertilizer schedule for the cover crops under oil palm during 2010- 2012

Application times	Mucuna bracteata, Pueraria javanica+Centrosema pubescens, Calopogonium caeruleum+Centrosema pubescens	Axonopus compressus
Planting hole	Rock Phosphate (9 kg ha^{-1})	-
1MAP	NPK green (40 kg ha^{-1})	NPK green (180 kg ha^{-1})
2 MAP	Rock Phosphate (100 kg ha^{-1})	NPK green (180 kg ha^{-1})
4 MAP	Rock Phosphate (100 kg ha^{-1})	-

MAP= Months after planting cover crops

A. compressus 2 WAP

A. compressus 3 MAP

M. bracteata 2 WAP

M. bracteata 6 MAP

P. javanica + C. pubescens 2WAP

P. javanica + C. pubescens 9MAP

C. caeruleum + C. pubescens 2 WAP

C. caeruleum + C. pubescens 9 MAP

Un-Weeded 9MAP

Weeded 9MAP

Fig. 1: *A. compressus*, *M. bracteata*, *P. javanica + C. pubescens*, *C. caeruleum + C. pubescens*, Un-Weeded and Weeded establishment in different times after planting
WAP: Week After Planting, MAP: Month after planting

A. compressus sown at a density equivalent to 5000 m^2 sod ha^{-1} obtained full coverage by about 3 months after planting (MAP). The *M. bracteata* growth rate, at a density equivalent to 680 plants ha^{-1}, became rapid at about 4 MAP into the field and attained about 100% ground coverage after 6 MAP. The *C. caeruleum + C. pubescens* and *P. javanica + C. pubescens* mixtures started to grow vigorously 6 MAP. The mixtures attained a coverage of 100% of the sown area at 9 MAP, with the planting densities of 12:3 kg ha^{-1} (ratio 4:1) and 3:3 kg ha^{-1} (1:1), respectively.

Cover Crop Biomass

The cover crop shoot dry matter production increased slowly in the first year of planting, showed a rapid rise at 15 MAP and peaked at 21 MAP before declining slightly at 24 MAP (Table 3). The litter showed an increasing trend as the cover crops became older. Litter production peaked at 24 MAP. The total biomass production showed a rapid rise at 15 MAP similar to shoot production and produced the highest total biomass at 21 and 24 MAP (Table 3).

Table 2: Month averages of daily maximum temperature, minimum temperature and rainfall at UPM during two years experiment

Year	Month	Maximum Temperature (°C)	Minimum Temperature (°C)	Rainfall (mm/day)
2010	September	33	24	15
	October	34	24	1.8
	November	33	24	9.9
	December	32	23	6.7
2011	January	34	23	6.1
	February	33	23	8
	March	33	23	5.8
	October	33	24	13
	November	32	23	9.1
	December	34	23	9
2012	January	34	24	2.6
	February	33	23	4.1
	March	33	23	5.8
	April	34	23	8.6
	May	34	24	4.1
	June	33	23	2.8
	July	33	23	2.6
	August	33	24	3.2
	September	33	23	11

Table 3: Shoot, litter and total biomass production of the cover crops at different sampling dates

Sampling date	Cover crop biomass (g m^{-2})		
	Shoot	Litter	Total
9 MAP	358b	143b	502d
12 MAP	348b	222b	570cd
15 MAP	459ba	256b	715abc
18 MAP	402ba	273b	676bcd
21 MAP	517a	264b	782ab
24 MAP	448ab	439a	888a

Means within columns followed by same letters are not significantly different at P = 0.05 according to Tukey's test. MAP= Months after planting

There were significant differences among shoot, litter and total biomass production in cover crops at the different sampling dates (Table 4). The litter in the cover crop treatments showed an increasing trend as the sampling date increased from 9 MAP to 24 MAP. After the first year, the leaf litter dry matter increased, but was not higher than the corresponding shoot dry matter. The litter production in *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* treatments were lower than the *A. compressus* and *M. bracteata* plots at the early sampling times (Table 4). *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* treatments showed significant differences in litter production with *A. compressus* and *M. bracteata* until 18 MAP, when the highest litter production was found in *M. bracteata* plots (493 g m^{-2}), while *C. caeruleum* + *C. pubescens* had the lowest (166 g m^{-2}). At 21 and 24 MAP the cover crops did not show significant differences in litter production. The shoot production in cover crops did not exhibit differences from 12 MAP, while at 9 MAP *A. compressus* had the highest shoot biomass (582 g m^{-2}) and *C. caeruleum* + *C. pubescens* had the lowest (165 g m^{-2}), followed by *M. bracteata* (382 g m^{-2}) and *P. javanica* + *C.*

pubescens (295 g m^{-2}) treatments. The total cover crop biomass varied significantly between the cover crop treatments at 9, 12, 15 and 18 MAP, while there were no differences at 21 and 24 MAP. At 24 MAP cover crop litter production increased substantially in *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* cover crop treatments (Table 4). The cover crops produced large amounts of total shoot and litter biomass of up to 500 g m^{-2} each in 18 months and up to 800 g m^{-2} of shoot and litter at 24 MAP.

Treatment (Weed Control) Efficiency

The cover crops systems significantly affected weed biomass and density under the oil palms (Table 6). Weed biomass and density varied significantly between the cover crops and un-weeded treatments at all sampling dates, but there was no significant difference between the cover crop treatments. At 9 months after planting (MAP) (i.e., as all cover crops were completely established), the cover crop treatments had lower weed dry weights and lower weed density than the un-weeded plots. On average, weed dry weight and density in the cover crop plots were 4.3 g m^{-2} and 7.4 weeds m^{-2}, while the corresponding values recorded were 254.6 g m^{-2} and 255.3 weeds m^{-2} in the un-weeded plots, respectively. Thus, the cover crops decreased weed biomass by 98% and weed density by 97% compared to un-weeded plots. At 12 MAP, weed dry weight reduction due to planting of different cover crops ranged from 98 to 99%, while weed density was reduced by 97-99% (Table 5). Response in weed biomass and density to different cover crop treatments at 15 and 18 MAP followed the same trend (Table 5). At 24 MAP, weed dry weight ranged between 1.8 and 5.93 g m^{-2} and weed density was between 1.33 and 12.67 plants m^{-2}. The cover crop treatments provided satisfactory weed control, while in the un-weeded plot the corresponding values were 734.7 g m^{-2} and 502.33 plants m^{-2} (Table 5).

Weed species responded differently to cover crop treatments (Table 6). Cover crops were found to be effective in controlling most of the weed species compared to un-weeded plots. Between the cover crop treatments, *M. bracteata* was less effective against *Paspalum conjugatum*, although *M. bracteata* plots had significantly lower *P. conjugatum* biomass than un-weeded plots. *P. conjugatum* produced 3 g m^{-2} biomass in the *M. bracteata* treatment, while 0, 0 and 0.78 g m^{-2} were produced in *A. compressus*, *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* treatments, respectively. *C. caeruleum* + *C. pubescens* performed poorly in suppressing *Mimosa pudica*. *Mimosa pudica* biomass in *C. caeruleum* + *C. pubescens* plots was 1.48 g m^{-2}, which was not significantly different from the un-weeded control. *Mimosa pudica* produced 0.38, 0 and 0 g m^{-2} biomass in *A. compressus*, *M. bracteata* and *P. javanica* + *C. pubescens* treatments, respectively, which was significantly different from the un-weeded control (Table 6).

Table 4: Shoot, litter and total biomass (g m^{-1}) production in different cover crop systems under oil palm at sampling dates

Cover crop	Cover crops dry weight (g m^{-2})																	
	9 MAP			12 MAP			15 MAP			18 MAP			21 MAP			24 MAP		
	Shoot	Litter	Total	Shoot	Litter	Total	Shoot	Litter	Total	Shoot	Litter	Total	Shoot	Litter	Total	Shoot	Litter	Total
A. compressus	582a	233a	815a	478a	400a	878a	457a	447a	904a	491a	235ab	726a	539a	270a	808a	320b	373a	693a
C. caeruleum + C. pubescens	165d	68c	233d	188a	73b	261c	470a	183b	653a	425a	166b	590ab	402a	226a	628a	460a	388a	848a
M. bracteata	382b	208b	589b	357a	325a	682ab	550a	302a	851a	377a	493a	870a	491a	242a	733a	513a	564a	1077a
P. javanica + C. pubescens	295c	35d	330c	370a	93b	463bc	355a	131b	486b	346a	188b	534b	640a	320a	960a	502a	434a	936a

Means within columns followed by the same letter are not significantly different at P = 0.05 according to Tukey's test
MAP= Months after planting

Table 5: Weed biomass and weed density in different cover crop systems at sampling dates

Sampling date	Treatments	Total weed biomass (g m^{-2})	Weed biomass control (%) by cover crops	Total weed density (no m^{-2})	Weed density control (%) by cover crops
9 MAP	*A. compressus*	2.00b	99.2	2.66b	98.95
	C. caeruleum + C. pubescens	6.87b	97.3	13.33b	94.77
	M. bracteata	5.73b	97.7	4.67b	98.17
	P. javanica + C. pubescens	4.74b	98.1	10.67b	95.82
	Un-Weeded	254.63a		255.33a	
12 MAP	*A. compressus*	10.59b	98.6	2.67b	99.5
	C. caeruleum + C. pubescens	4.47b	99.4	10.67b	98.03
	M. bracteata	8.79b	98.9	5.33b	99.02
	P. javanica + C. pubescens	3.07b	99.6	13.33b	97.54
	Un-Weeded	804.52a		544.00a	
15 MAP	*A. compressus*	6.47b	98.3	11.33b	97.29
	C. caeruleum + C. pubescens	1.64b	99.5	8.00b	98.09
	M. bracteata	1.20b	99.6	2.67b	99.30
	P. javanica + C. pubescens	3.38b	99.1	7.33b	98.25
	Un-Weeded	395.56a		419.55a	
18 MAP	*A. compressus*	2.61b	99.5	7.66b	98.27
	C. caeruleum + C. pubescens	1.64b	99.7	8.00b	98.2
	M. bracteata	7.03b	98.8	11.33b	97.45
	P. javanica + C. pubescens	3.51b	99.4	7.33b	98.35
	Un-Weeded	630.55a		445.00a	
24 MAP	*A. compressus*	1.80b	99.7	1.33b	99.73
	C. caeruleum + C. pubescens	4.13b	99.4	6.67b	98.67
	M. bracteata	4.13b	99.4	9.00b	98.20
	P. javanica + C. pubescens	5.93b	99.1	12.67b	97.47
	Un-Weeded	734.70a		502.33a	

Means within columns of each sampling date followed by same letter are not significantly different at P = 0.05 according to Tukey's test

Table 6: Mean weeds biomass and weed density of the different weed species in different cover crop systems

Treatments	Weed species biomass and density									
	BORLA	MIMPU	ASYGA	AXOCO	SCLSU	PASCO	CLIHI	MELMA	OTTNO	Total
Biomass										
A. compressus	0.43b	0.38b	4.93b	0.00b	0.00b	0.00c	0.00b	0.00b	0.00b	5.74b
C. caeruleum + C. pubescens	0.83b	1.48ab	1.30b	1.23b	0.14b	0.00c	0.00b	0.00b	0.00b	4.98b
M. bracteata	0.00b	0.00b	1.11b	1.36b	0.20b	3.00b	0.04b	0.00b	0.71b	6.46b
P. javanica + C. pubescens	0.00b	0.00b	1.50b	2.75b	0.06b	0.78bc	0.00b	0.44b	0.26b	5.74b
Un-Weeded	5.20a	15.73a	22.33a	319.12a	3.20a	329.24a	6.06a	11.06a	20.55a	733.03a
Density										
A. compressus	1.14bc	0.78a	4.54b	0.00b	0.00b	0.00b	0.00b	0.00b	0.00b	6.46b
C. caeruleum + C. pubescens	1.20b	3.69a	3.38b	2.62b	0.25b	0.00b	0.00b	0.00b	0.33b	11.47b
M. bracteata	0.00c	0.00a	1.83b	2.08b	0.67b	1.83b	0.04b	0.00b	1.23b	7.68b
P. javanica + C. pubescens	0.00c	0.00a	3.46b	6.50b	0.00b	1.50b	0.00b	0.67b	1.00b	13.13b
Un-weeded	9.85a	22.73a	20.80a	318.23a	1.58a	111.00a	5.30a	7.27a	40.10a	536.78a

BORLA= *Borreria latifolia* (Aubl.) K. Schum, MIMPU= *Mimosa pudica* L., ASYGA= *Asystasia gangetica* L., AXOCO= *Axonopus compressus* (Sw.) Beauv, SCLSU= *Scleria sumatrensis* Retz, PASCO= *Paspalum conjugatum* Bergius, CLIHI= *Clidemia hirta* L., MELMA= *Melastoma malabathricum* L., OTTNO= *Ottochloa nodosa* (Kunth) Dandy
Means within columns of biomass and density followed by same letters are not significantly different at P = 0.05 according to Tukey's test

Phenolic Compounds in the Soil

The concentration of acetone extractable phenolics in the treated soils was higher than the water extractable phenolics (Table 7). Water and acetone extractable phenolic compounds in the soils under the various cover crops increased with increasing sampling time (Table 7). However, two distinct trends in acetone extractable phenolic were observed among the treatments. In the *A. compressus* and *C. caeruleum* + *C. pubescens* treatments there was about a 4.5 – fold increase, while there was a 1.2 -fold increase in the *M. bracteata* and *P. javanica* + *C. pubescens* treatments at 24 MAP. In the un-weeded treatment the acetone extractable phenolics decreased at 24 MAP compared to 12 MAP.

At 12 MAP, the highest water extractable phenolic content was found in the *A. compressus* (2.9 ppm) and *M. bracteata* (3.9 ppm) treatments, while other treatments showed near zero phenolic content. At 12 MAP, the highest acetone extractable phenolic content was found in the *M. bracteata* (293.4 ppm) and *P. javanica* + *C. pubescens* (260.1 ppm) treatments, while lower amounts of about 70 ppm were obtained in other treatments. At 24 MAP, the *M. bracteata* treatment had the highest water extractable phenolics (4.5 ppm), while the *P. javanica* + *C. pubescens* treatment had the lowest (2.5 ppm). There were significant differences only between the un-weeded and other treatments in terms of acetone extractable phenolics at 24 MAP. The un-weeded treatment had 45.9 ppm acetone extractable phenolics, while the others had a mean of about 350 ppm.

Phenolic Compounds in Cover Crop Tissues

Water and acetone extractable phenolics of the cover crop shoots and litter are presented in Table 8. The samples were collected at 24 MAP. The level of water and aceton extractable phenolics in cover crop shoot was higher than those in the litter. The highest water extractable phenolics in cover crop litter was found in the *C. caeruleum* + *C. pubescens* (172 ppm) treatment, followed by *P. javanica* + *C. pubescens* (163 ppm), *M. bracteata* (105 ppm) and *A. compressus* (100 ppm) treatments. Water extractable phenolics in the different cover crop shoots ranged from 687 ppm in *P. javanica* + *C. pubescens* to 400 ppm in the *A. compressus* treatment. *C. caeruleum* + *C. pubescens* and *M. bracteata* produced 641 and 403 ppm, respectively. The acetone extractable phenolic content of the cover crop litter can be ranked as follows: *P. javanica* + *C. pubescens* (322 ppm) > *M. bracteata* (280 ppm) > *A. compressus* (180 ppm) > *C. caeruleum* + *C. pubescens* (156 ppm). *P. javanica* + *C. pubescens* had maximum acetone extractable phenolics content in the shoots (1543 ppm), followed by *C. caeruleum* + *C. pubescens* (620 ppm), *M. bracteata* (433 ppm) and *A. compressus* (423 ppm).

Discussion

The cover crops were established differently in the field. The *A. compressus* grew well from the start of the experiment, and covered entire plots within 3 months. The initial establishment of *M. bracteata* during the first two to three months was quite slow, because the seedlings took time to recover from transplanting shock (Chua *et al.*, 2007). However, the *M. bracteata* started to grow vigorously 4 months after field planting and attained 100% ground cover after 6 months. Establishment of *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* took a longer time, namely 9 months. Fast establishment of *M. bracteata* and slow establishment of conventional legumes have been reported in many studies. Agamuthu *et al.* (1980) reported that after planting *P. javanica* + *C. pubescens*, the amount of legume coverage exceeded 95% of the sown area only after 26 months. Chua *et al.* (2007) observed that

Table 7: Water and acetone extractable phenolics in soil under different cover crop systems at sampling dates

| Treatments | Phenolic compounds in soil | | | |
| | 12MAP | | 24MAP | |
	Water extractable	Acetone extractable	Water extractable	Acetone extractable
A. compressus	2.9a	71.6b	3.4ab	353.0a
C. caeruleum + *C. pubescens*	0.1b	78.7b	3.4ab	354.2a
M. bracteata	3.9a	293.4a	4.5a	334.0a
P. javanica + *C. pubescens*	0.0b	260.1a	2.5b	378.8a
Un-Weeded	0.0b	70.1b	3.2ab	45.9b

Means within columns followed by same letter are not significantly different at P = 0.05 according to Tukey's test

Table 8: Water and acetone extractable phenolics in different cover crop systems tissues at 24 MAP

| Treatments | Phenolic compounds in cover crop tissues | | | |
| | Litter | | Shoot | |
	Water extractable	Acetone extractable	Water extractable	Acetone extractable
A. compressus	100	180	400	423
C. caeruleum + *C. pubescens*	172	156	641	620
M. bracteata	105	280	403	433
P. javanica + *C. pubescens*	163	322	687	1543

MAP= Months after planting

M. bracteata covered about 80 to 90% of the field in the first year after planting. *M. bracteata* plants grew well from the start of the experiment, while *P. javanica* establishment was initially poor in the field (Mendham *et al.*, 2004). The density of *M. bracteata* does not appear to have an effect on speed of establishment. Lee *et al.* (2005) suggested 500 to 600 plants per hectare for *M. bracteata* in a poorer growing environment to achieve full ground coverage within six to nine months after establishment. At a density equivalent to 68 seedlings per hectare full coverage was obtained in about 12 months after planting (Mathews and Saw, 2007). Ling *et al.* (1979) demonstrated the speed of cover crop establishment is very important such as with a ground cover both runoff and erosion in an oil palm plantation with a 10° slope declined three and eight fold, respectively. Cover crop with about 90-100% ground coverage could decrease soil erosion and runoff to negligible levels, similar to those under primary forests (Ling *et al.*, 1979).

Cover crops that established sooner, produced more shoot biomass in the first year. Thus, *A. compressus* produced the highest shoot biomass (582 g m^{-2}), while *C. caeruleum* + *C. pubescens* produced the lowest (165 g m^{-2}). *M. bracteata* and *P. javanica* + *C. pubescens* produced 382 and 295 g m^{-2} of shoot biomass at 9 MAP, respectively. The shoot production in cover crops did not exhibit differences during the first year after planting the cover crop. In general, the shoot dry matter production in conventional legumes increased slowly during the first year of planting before showing a rapid rise and peaking in the second year. *M. bracteata* and *A. compressus* until 18 MAP produced higher leaf litter dry weights compared to conventional cover crops, but subsequently the conventional cover crops also increased litter production. The total cover crop biomass showed significant variation between cover crop treatments at 9, 12, 15 and 18 MAP. However, at 21 and 24 MAP, when litter production increased substantially in *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* there was no significant variation between the cover crops treatments. After the first year, the leaf litter dry matter increased but was not higher than the corresponding shoot dry matter. Shaharudin and Jamaluddin (2007) had reported that *M. bracteata* produced 19.1 t ha^{-1} dry matter comprising of 10.9 t ha^{-1} of green vegetative matter and 8.2 t ha^{-1} of leaf litter. Legumes usually begin to fix nitrogen after growing for two to three weeks, whereas leaf litter accumulation commences after about six months (Broughton, 1977).

The weed densities in the un-weeded plots were 255, 544, 419, 445 and 502 plants m^{-2} at 9, 12, 15, 18 and 24 MAP, with the corresponding biomasses of 254, 804, 395, 630 and 734 g m^{-2}, respectively. Weeds are a perennial problem in oil palm plantations. The occurrence of a wide range of weeds also causes difficulties in their eradication. The high weed pressure as observed in this study confirms the findings of Mathews and Saw (2007) who reported 7.5 t ha^{-1} biomass production by natural cover plants over 72 months after planting, while *M. bracteata* produced 15 t

ha^{-1}. In the present study, total biomass production in the un-weeded treatment at 24 MAP was about 7.5 t ha^{-1}, which did not show differences with other cover crop treatments at this sampling date. *A. compressus*, *C. caeruleum* + *C. pubescens*, *M. bracteata* and *P. javanica* + *C. pubescens* treatments produced about 7, 8.5, 10 and 9 t ha^{-1} biomass at 24 MAP, respectively. *M. bracteata* biomass production was similar to Chua *et al.* (2007), who reported 11.2 t ha^{-1} total dry matter production in two-year old *M. bracteata*.

Cover crops were found effective in arresting the weed population and growth at all sampling times. The percentage of weed dry weight and weed density that declined with the cover crop treatments in comparison to the un-weeded treatment ranged between 97.3 - 99.9% and 94.77 - 99.73%, respectively. The cover crops are in fact effective in controlling the weeds. *M. bracteata* is highly competitive with common weeds found in plantations (Kothandaraman *et al.*, 1989). *P. javanica* in a 2 year experiment reduced the germinating weed seed percentage by 90.3, 94.3 and 95% in the top three soil layers (Sumith *et al.*, 2009). Cover crops and the residues they produce suppress weeds directly through a variety of physical and biological means (Teasdale, 1996; Sarrantonio and Gallandt, 2003). The leguminous cover crops control the weeds by creeping over weeds and smothering them. Leguminous cover crops can also cause physical suppression as they have a climbing habit (Corley and Tinker, 2003). Cover crops can affect the loss of seeds from the seed bank by influencing seed germination and decay (Cousens and Mortimer, 1995), shading out weed seeds requiring light for germination, and by allelopathy (Rice, 1984; Madumadu, 1991). Cover crops can also contribute indirectly to weed management by promoting a population of beneficial weed seed predators (Carmona and Landis, 1999). Higher rates of seed predation have been found in plots with vegetative cover, compared to those without vegetation (Reader, 1993; Gallandt *et al.*, 2005). Existence of phenolic compounds in cover crops was confirmed in the present study. There was not a considerable amount of water extractable phenolics detected in soils under cover crops. This is most likely due to the high rainfall. Amount of acetone extractable phenolics was high and was about 350 ppm under cover crops, which was much more relative to the un-weeded control (46 ppm). There were also high phenolic contents in the litter and shoots of cover crops, and *P. javanica* had a higher phenolic content than other cover crops. The allelopathic effects of cover crops have been previously reported (Manidool, 1992; Corley and Tinker, 2003).

The fast growth rate of *A. compressus* and *M. bracteata* enables them to initially compete successfully with most vegetation found in oil palm plantations, while *C. caeruleum* + *C. pubescens* and *P. javanica* + *C. pubescens* took several months to establish a good level of cover. The weed density was high at the initial stages in these conventional legume plots compared to *A. compressus* and *M. bracteata* and declined gradually. With time, *C.*

caeruleum, *C. pubescens* and *P. javanica* regenerated from seeds and formed a good ground cover, thereby suppressing the weed population. In fact, there was a consistent inverse relationship between cover crop biomass and total weed biomass. Maintaining a uniformly thick canopy can control weeds. Poor cover crop establishment and sparse canopy increased weed biomass in cover crop treatments (Baumgartner *et al.*, 2007). The sparse spatial arrangement and the thin canopy of cover crops allowed for open spaces where weeds could colonize or germinate from the seed bank (Potthoff *et al.*, 2005). The importance of reducing weed competition on the dry matter production of *M. bracteata* was illustrated by Ng *et al.* (2006). They reported that the poor growth of *M. bracteata* in the mixed system in the first year was mainly ascribed to competition from weeds. Chung and Balasubramaniam (1996) reiterated that one of the purposes of planting legumes was to suppress weeds, but the legumes cannot do this if they are sown in weed infested ground and weed suppression is essential for good cover establishment. Normally, cover crops should be sown on ground already cleared of other vegetation by ploughing, cultivation or spraying. The weed-free period can be prolonged by hand-weeding, unless labour shortages make this difficult, in which case glyphosate or other herbicides are used. Mechanical weeding is very convenient if the conditions are satisfactory (Corley and Tinker, 2003).

The present study included four cover crops, all of which provided good weed control. However, many leguminous cover crops have a climbing habit and require regular pruning around the tree base to prevent them from smothering the tree crop. Hence, maintenance of perennial legumes especially *M. bracteata* can be labour intensive, because *M. bracteata* is a vigorous legume that can rapidly spread via branching from each node in the runners very quickly and compete with the tree for light much more than the other legumes. Besides, the results of the present study indicated that *A. compressus* was a suitable cover species for suppressing weeds in oil palm plantations. Therefore, *A. compressus* could be considered as a suitable candidate as a cover crop under oil palm compare to conventional legume cover crops and *M. bracteata*. Research is needed to further explore this possibility in order to reduce the use of herbicides in oil palm plantation.

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