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Full Length Article

Effect of Cover Crops on Weed Community and Oil Palm Yield

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Abstract

Sustainable weed management in oil palm plantation has been a challenge now a day. Weed suppression by cover cropping is considered as a viable alternative to herbicidal control. This study0020was, therefore, conducted during 2010-2012 in a Malaysia oil palm plantation to characterize oil palm weed communities and evaluate oil palm yield under four different perennial cover-crop systems. Experimental treatments included four different cover crop combinations such as *Axonopus compressus*, *Calopogonium caeruleum* + *Centrosema pubescens*, *Mucuna bracteata*, *Pueraria javanica* + *Centrosema pubescens*, and herbicidal control by glufosinate-ammonium and weedy control. Weed composition in the un-weeded treatment was different from that of cover crop treatments. The un-weeded treatment favored *Paspalum conjugatum* and *A. compressus* as the dominant species. In the *A. compressus* and *C. caeruleum* + *C. pubescens* treatments the associated weed species with highest dominance was *Asystasia gangetica,* while the weeds *A. compressus* and *A. gangetica* were associated with *M. bracteata* and *P. javanica* + *C. pubescens* treatments. In the weeded treatment receiving 6 sprays of glufosinate-ammonium over the two years, *B. latifolia* was dominant. The *A. compressus* cover treatment had the lowest species richness and diversity. Weeded plots had lowest yield, bunch number tree^{-1} and bunch weight during the 18-24 MAP. The study confirms variation in weed community in oil palm plantation under different cover-crop systems and thus, contributes to improving current understanding of weed community structures and may help formulate sustainable weed management strategy for oil palm plantation.

Keywords: Oil palm; Cover crop; Weed community; Yield

Introduction

Tropical climates with ample sunshine, heat and moisture mean that weeds thrive. In established oil palm plantations, noxious weeds compete strongly against the oil palm for nutrients, moisture, and sunlight, and shade the oil palm plants, and eventually cause yield depression (Azahari *et al.*, 2004; Pride, 2012). As a result of strong competition from weeds, yield losses recorded range from 6 to 20% (Sahid *et al.*, 1992). 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.

The species composition of weed communities in oil palm areas varies according to climate, the environmental conditions, and husbandry methods (Corley and Tinker, 2003). Regardless of the composition, weeds compete with oil palm for resources, especially during establishment and early growth stages, affecting its growth and yield and obstructing routine estate practices (Azahari *et al.*, 2004; Rosli *et al.*, 2010).

Though herbicide application is the most cost effective and widely used weed control method (Wibawa *et al.*, 2010), its use is becoming increasingly unpopular with the public (Farooq *et al*., 2011). Replacement of soft weeds by noxious weeds, destroy habitat for predators of insect pests, eradicate useful insects, pollute natural resources and weed resistance are the reasons to make herbicide use unpopular in commercial agriculture (Adam *et al.*, 2010; Chey, 2006).

Oil palm is increasingly under world scrutiny with emphasis on sustainable cultivation. Cultivation of cover crops qualifies as part of a sustainable agricultural practice. Leguminous cover crops are grown as an intercrop, to co-exist with the oil palm following jungle clearing and planting or replanting, to provide complete cover to an otherwise bare soil to protect the soil from the forces of erosion. The leguminous cover crops also perform multiple functions such as reducing soil water evaporation, runoff losses, soil erosion, improve or maintain soil fertility and recycling of nutrients. 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). The ground vegetation in oil palm plantations is managed not with weed control as the main priority. Nonetheless, such practices

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have been used to influence weed communities in annual systems (Smith and Alli, 2007). Few studies have attempted to determine the effect of cover crops on weed community structure in perennial systems (Gago *et al.,* 2007; Baumgartner *et al.*, 2008). There is some evidence suggesting that intercropping could modify weed species assemblage (Poggio, 2005). Individual crops that constitute an intercrop can differ in the use of resources spatially or temporally, and result in a more complementary and efficient use of resources than when they are grown in monocultures and thus decrease the amount available for weeds (Liebman, 1988).

It was hypothesized that cover crop systems would produce a shift in the weed community structure and diversity as different cover crops would create microhabitats that would differentially benefit weed species. Such information would contribute towards improved understanding of how current crop–weed communities are assembled, decrease the need for herbicides, and may improve the sustainability of Malaysia's oil palm production systems. Although, weed management by cover cropping is gaining popularity in oil palm plantation in Malaysia but, information on weed management in oil palm plantation by cover crops especially in Malaysian oil palm industry is scanty. Moreover, the potentiality of cover cropping as a mean of weed management in oil palm industry has not been fully explored. Hence, the present study was designed to examine the influence of four cover crop systems on the composition and diversity of oil palm weed communities and their subsequent effect on oil palm yield.

Materials and Methods

Experimental Details and Treatments

Experimental site: The experiment was conducted in an existing four-year old D × P oil-palm plantation at Field 15, Universiti Agriculture Park, Universiti Putra Malaysia (UPM) (3º02'N, 101º42'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%. Table 1 shows the weather data during the experiment.

Land preparation: 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 interrows was ploughed to a depth of approximately 15 cm and rotovated to prepare the seedbeds.

Experimental layout: Each treatment plot 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).

Good viable seeds of *M. bracteata* were identified based on of the smooth seed coat with variegated brown colorations over it. *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. The polybags were carefully removed without breaking the soil core and the seedlings were planted. The planting points were filled with soil to ground level and the soil around was consolidated by stamping with the feet. *M. bracteata* was planted at an interrow and intrarow spacing of 1.5 m apart at a density of 680 seedling ha^{-1}.

A. 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 and Weeding

Essential fertilizers were applied to cover crops in all plots, at different times (Goh and Chiu, 2007). Oil palms received fertilizer based on soil analysis. 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. 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.

Observations

An initial weed vegetation analysis was conducted in the experimental plots prior to establishing the cover crop treatments. The analysis was conducted to determine the composition of weeds. The experimental area was divided into 3 sections, which represented blocks in the experimental design. Weed samples were collected by randomly placing a 50 cm by 50 cm quadrate at 10 locations per block. Absolute and relative weed densities and dry weight of each weed type were recorded to compute summed dominance ratio (SDR) and Sorenson's index (S). All above ground weed vegetation was harvested and separated by weed species, dried in an oven at 75^{o}C for 72 hours and dry weights were recorded. Weed density and weed dry weights were expressed as number m^{-2} and g m^{-2}, respectively. Dominant weed species were identified using the summed dominance ratio (SDR) (Wibawa *et al.*, 2007). The relative contribution of different weed groups (broadleaved and grasses) to the weed vegetation was also calculated.

The major or dominant weed species were determined by computing SDR values (Wibawa *et al.*, 2007) as follows:

$$\text{SDR of a species} = \frac{\text{Relative density} + \text{Relative dry weight}}{2}$$

Relative density and relative dry weight were determined as follows:

$$\text{Relative density of a species} = \frac{\text{Absolute density of a species}}{\text{Total absolute density of all species}} \times 100$$

$$\text{Relative dry weight of a species} = \frac{\text{Absolute dry weight of a species}}{\text{Total absolute dry weight of all species}} \times 100$$

Absolute density of a species was equal to the total number of plants of that species in the sample plot and absolute dry weight of a species was the total biomass of that species in the sample plot.

Similarity in occurrence of weed species between blocks was determined using Sorenson's index of similarity (S):

$$S = (\frac{2J}{A + B}) \times 100$$

Where, S = Index of association between blocks A and B, J = No. of weed species common in both blocks A and B, A = No. of weed species present in block A, B = No. of weed species present in block B. Sorenson's index values indicate homogeneity of weed communities among the blocks. Bonham (1989) divided vegetation condition into 5 classes, namely, excellent (91-100%), good (71-90%), fair (56-70%), poor (45-55%) and unacceptable (<45%). According to Bonham (1989) homogeneity value of >71% (good to excellent homogeneity) is a required condition for carrying out weed control experiments.

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 25 cm by 25 cm quadrate at 8 locations in each experimental plot. All above ground weed vegetation was harvested and separated by weed species, dried in an oven at 75^{0}C for 72 h, and dry weights were recorded. Weed density and weed dry weights were expressed as no m^{-2} and g m^{-2}, respectively. Absolute and relative weed densities and dry weight of each weed type was recorded to compute summed dominance ratio (SDR).

Species richness (*S*) and diversity (Shannon's diversity, *H'*) were calculated separately with the use of the following formula (Baumgartner *et al.*, 2008):

S = number of non-zero species in a treatment

$$H' = -\sum_{i}^{s} pi \log pi,$$

Where, *pi* is the proportion of *s* made up of the *i*th species. For *H'*, the treatment with the highest value has a higher *S* or has more species present in equal abundance than the other treatments, or both.

For the estimation of water-soluble phenolics, 5 g of cover plant tissues, which were collected at 24 months after planting, were selected. The 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_2CO_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 tissues, the same protocol was used (except for the extraction). The extracts were prepared using 70% acetone.

The fresh fruit bunch (FFB) number was determined on per palm basis. Mean bunch weight was also recorded. Data were collected from the two palms in each plot. The oil palm yield in terms of kg of FFB per palm per year was calculated.

Statistical Analysis

Analyses of variance (ANOVA) were performed to determine the effects of treatments and sampling dates on variables. 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

Weed Community Structure at the Experimental Locality at the Early Stage of the Experiment

In the present study, the weed vegetation analysis at the early stage recorded 10 weed species, indicating a composition of mixed weed species in the experimental area (Table 2). The composition was dominated by broadleaf species with six species, and only four grass species. The weeds spread over seven plant families. The dominance of broadleaf species covering the area was obvious with a total relative density of 72.7% and relative dominance of 76.4% (Table 2). About 85% of the weed composition was represented by five species in terms of their relative density and dominance. Among these, three species were represented by broadleaves and two species were grasses. Meanwhile, two species were found to dominate the locality based on their relative density and dominance. This consisted of a broadleaf species (*Borreria latifolia* (Aubl.) K. Schum) and a grass species (*Axonopus compressus* (Sw.) Beauv.). The dominance of *B. latifolia* was obvious with the high relative density (58%) and dominance (60%) compared to other species present, and was followed by *A. compressus* (with corresponding values of 13% and 11%, respectively). Two species were rated as being the least dominant. These include *Melastoma malabathricum* L. (broadleaf) with 0.2% and 0.8%, and *Macaranga* sp. (broadleaf) with 0.6% and 0.4% relative density and dominance, respectively. Further analysis showed that relative composition of broadleafs and grasses, across the site during the early stage of the experiment, were 74.56 and 25.44%, respectively (data not shown). Thus, it was apparent that the oil palm plantation was dominated by broadleaf weeds and the most dominant species was *B. latifolia*. The experimental locality indicated a composite of mixed weeds (of broadleaves and grasses), with the broadleaves being more dominant over the grasses. Sorenson's index of similarity among different blocks ranged from 70 to 88%.

Weed Communities Structure during the Experiment

The experimental plots were infested with broadleaved and grass weeds. The weed vegetation analysed after 2 years recorded 12 weed species. A few perennial weeds, *Cleome gynandra* L., *Macaranga* sp. and *Scoparia dulcis* L. which had low frequencies and/or inconsistent occurrence, made it difficult to identify their species-treatment associations. Treatments were distinguished by the same nine perennial grasses and broadleaved weed species: *Asystasia gangetica*, *Axonopus compressus*, *Borreria latifolia*, *Melastoma malabathricum*, *Mimosa pudica*, *Ottochloa nodosa*, *Paspalum conjugatum* and *Scleria sumatrensis.* Summed dominance ratios (SDR) revealed significant community differences between treatments (Table 3).

In the *A. compressus* treatment, only *A. gangetica* was dominant (SDR 100) at 9 and 12 MAP (Table 3). At 15 MAP, *A. gangetica* (SDR 37.26) and *B. latifolia* (SDR 38.9) had similar dominance ratios, followed by *M. pudica* (SDR 23.55). The most dominant species at 18 MAP was *A. gangetica* (SDR 88.88), followed by *M. pudica* (SDR 22.22). *Asystasia gangetica* (SDR 100) was the only dominant weed at 24 MAP.

In the *C. caeruleum* + *C. pubescens* treatment, *A. compressus* and *B. latifolia* were the two most dominant species at 9 MAP (SDR 39), followed by *M. pudica* (SDR 23.7). At 12 MAP, *A. compressus* was observed to have the highest dominance (SDR 56.67), followed by *M. pudica* (SDR 42.34). The most dominant species at 15 MAP was *M. pudica* (SDR 60.73) followed by *A. gangetica* (SDR 39.26). A similar trend was observed at 18 MAP, with *M. pudica* having an SDR of 58.8 and *A. gangetica* having an SDR of 41.19. At 24 MAP, *A. gangetica* was the most dominant.

In the *M. bracteata* treatment, *P. conjugatum* was the most dominant at 9 MAP (SDR 68.68), followed by *A. compressus* (SDR 31.31). At 12 MAP, *P. conjugatum* had a similar trend (SDR 61.59), followed by *O. nodosa* (SDR 32.08). *O. nodosa* was the only dominant species at

Table 1: Year average of relative humidity, maximum temperature, minimum temperature, rainfall, evaporation and sunshine hours at UPM during experiment

Year	Relative Humidity (%)*	Maximum Temperature (^oC)	Minimum Temperature (^oC)	Rainfall (mm/day)	Evaporation (mm/day)	Sunshine (hrs/day)
2010	94.2	33.2	23.6	8.4	4.4	5.2
2011	93.8	33.2	23.3	8.5	3.8	5.9
2012	93.8	33.5	23.4	5.0	3.8	6.6

*date average during September 2010 - September 2012

Table 2: Weed species composition in the experimental locality at the early stages of the experiment

Scientific name	Family name	Weed type	RD (%)	RDW (%)	SDR (%)
Asystasia gangetica L.	Acanthaceae	Broadleaf	5.14	6.26	5.7
Axonopus compressus (Sw.) Beauv	Poaceae	Grass	12.94	8.91	10.92
Borreria latifolia (Aubl.) K. Schum	Rubiaceae	Broadleaf	58.11	59.86	58.99
Macaranga sp.	Euphorbiaceae	Broadleaf	0.59	0.41	0.50
Melastoma malabathricum L.	Melastomataceae	Broadleaf	0.20	0.84	0.52
Mimosa pudica L.	Fabaceae	Broadleaf	0.55	5.14	2.84
Ottochloa nodosa (Kunth) Dandy	Poaceae	Grass	4.71	3.27	3.99
Paspalum conjugatum Bergius	Poaceae	Grass	3.19	5.13	4.16
Scleria sumatrensis Retz	Cyperaceae	Grass	6.47	6.26	6.37
Scoparia dulcis L.	Scrophulariaceae	Broadleaf	8.09	3.93	6.01

RD= Relative density, RDW= Relative dry weight and SDR= Summed dominance ratio

Table 3: Summed dominance ratios of weed species in the different treatments at different sampling dates

	A. compressus					*C. caeruleum + C. pubescens*					*M. bracteata*				
	Sampling date (MAP)														
Scientific name	9	12	15	18	24	9	12	15	18	24	9	12	15	18	24
Asystasia gangetica L.	100	100	37.26	88.88	100			39.26	41.19	84.43	-	6.32	5.5	45.27	24.46
Axonopus compressus (Sw.) Beauv	-	-	-	-	-	38.6	56.67	-	-	-	31.31	-	-	14.37	75.53
Borreria latifolia (Aubl.) K. Schum	-	-	38.90	-	-	39.0	-	-	-	-	-	-	-	-	-
Clidemia hirta L.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Melastoma malabathricum L.	-	-	-	-	-	-		-	-	-	-	-	-	-	-
Mimosa pudica L.	-	-	23.55	22.22	-	23.7	42.34	60.73	58.80	-	-	-	-	-	-
Ottochloa nodosa (Kunth) Dandy	-	-	-	-	-	-	-	-	-	-	-	32.08	94.5	-	-
Paspalum conjugatum Bergius	-	-	-	-	-	-	-	-	-		68.68	61.59	-	22.15	-
Scleria sumatrensis Retz	-	-	-	-	-	-	-	-	-	15.56	-	-	-	18.20	-

- = not exist weed species
MAP= months after planting

	P. javanica + C. pubescens					Un-Weeded				
	Sampling date (MAP)									
Scientific name	9	12	15	18	24	9	12	15	18	24
Asystasia gangetica L.	-	12.7	33.55	35.15	47.83	0.39	6.42	1.11	1.32	4.11
Axonopus compressus (Sw.) Beauv	39.69	54.3	43.65	37.64	52.16	69.04	40.70	82.19	42.28	38.42
Borreria latifolia (Aubl.) K. Schum	-	-	-	-	-	3.76	3.09	4.88	-	-
Clidemia hirta L.	-	-	-	-	-	1.05	0.84	1.55	0.86	0.77
Melastoma malabathricum L.	-	-	23.1	27.12	-	1.75	1.16	1.80	2.39	1.35
Mimosa pudica L.	-	-	-	-	-	2.47	10.32	2.54	-	-
Ottochloa nodosa (Kunth) Dandy	-	32.8	-	-	-	-	6.38	2.84	10.25	3.85
Paspalum conjugatum Bergius	60.3	-	-	-	-	18.75	31.04	7.33	42.87	50.27
Scleria sumatrensis Retz	-	-	-	-	-	2.96	-	-	-	1.2

- = not exist weed species
MAP= months after planting

15 MAP (SDR 100). At 18 MAP, *A. gangetica* was the most dominant (SDR 45.27) followed by *P. conjugatum* (SDR 22.15), *S. sumatrensis* (SDR 18.2) and *A. compressus* (SDR 14.37). At 24 MAP, *A. compressus* (SDR 75.5) and *A. gangetica* (SDR 24.4) were the only two dominant weed species.

In the *P. javanica + C. pubescens* treatment, *P. conjugatum* (SDR 60.3) and *A. compressus* (SDR 39.69) were the two dominant weed species at 9 MAP. *A. compressus* (SDR 54.3) emerged as the first weed species at 12 MAP, followed by *O. nodosa* (SDR 32.8) and *A. gangetica* (SDR 12.7). At 15 MAP, *A. gangetica* was the most dominant (SDR 43.65), followed by *A. gangetica* (SDR 33.55) and *M. malabathricum* (SDR 23.1). A similar trend was observed at 18 MAP with *A. compressus* (SDR 37.64), *A. gangetica* (SDR 35.15) and *M. malabathricum* (SDR 27.12). At 24 MAP, *A. compressus* (SDR 52.16) and *A. gangetica* (SDR 47.83) were the two dominant weed species.

In the un-weeded treatment**,** *A. compressus* was the most predominant species (SDR 69.04) at 9 MAP. *P. conjugatum* emerged as the second most dominant weed species (SDR 18.75) followed by *B. latifolia* (SDR 3.76), *S. sumatrensis* (SDR 2.96) and *M. pudica* (SDR 2.47). At 12 MAP, *A. compressus* observed to have the highest dominance (SDR 40.7) followed by *P. conjugatum* (SDR 31.04), *M. pudica* (SDR 10.32), *A. gangetica* (SDR 6.42), *O. nodosa* (SDR 6.38) and *B. latifolia* (SDR 3.09). At 15 MAP, the highest SDR value (82.19) was recorded for *A. compressus* followed by *P. conjugatum* (SDR 7.33), *B. latifolia* (SDR 4.88), *O. nodosa* (SDR 2.84) and *M. pudica* (SDR 2.54). *A. compressus* and *P. conjugatum* were the two most predominant species at 18 MAP (SDR 42.28 and 42.87, respectively), followed by *O. nodosa* (SDR 10.25), and *M. malabathricum* (SDR 2.39). Of the total 12-recorded weed species in this experiment, only 7 species remained until 24 MAP in the un-weeded treatment. At 24 MAP, the grass weed species *P. conjugatum* (SDR 50.27) was the most predominant species in the un-weeded plots. *A. compressus* emerged as the second most dominant weed species (SDR 38.42). Among the broadleaf weed species, *A. gangetica* ranked third (SDR 4.11). The grass species, *O. nodosa* appeared as the fourth most dominant weed (SDR 3.85). Broadleaf weed species *C. hirta* (SDR 0.77) and *M. malabathricum* (SDR 1.35) and grass weed species *S. sumatrensis* (SDR 1.2) were not among the top most dominant weed species at the later part of the experiment in un-weeded treatment plots. Further analysis showed that the relative composition of broadleaved and grass weeds at the later part of the experiment in the un-weeded treatment was about 6.23% and 93.74%, respectively (data not shown). Thus, it was apparent that the ground vegetation under oil palm was dominated by grass weeds, and the most dominant species were *P. conjugatum* Bergius and *A. compressus* (Sw.) Beauv.

There was a species treatment association. The species present in the communities fell into one of the following categories: (1) ubiquitous among treatments (e.g. *A. gangetica* L.), (2) sporadically present in a given treatment (e.g. *Cleome gynandra* L.) and (3) dominant in certain treatments (e.g. *P. conjugatum* Bergius in the un-weeded treatment). In the *A. compressus* and *C. caeruleum* + *C. pubescens* treatments the weed community was associated with high dominance of *A. gangetica* weed species. *A. gangetica* was present in all treatments at 24 MAP. The weed community associated with the *M. bracteata* treatment was more closely similar to that of the *P. javanica* + *C. pubescens* treatment than to the *C. caeruleum* + *C. pubescens* treatment. *M. bracteata* was associated with high relative abundance of *A. compressus* and *A. gangetica*. *A. gangetica* and *A. compressus* were present in all treatments at 24 MAP, except that *A. compressus* was not present in the *C. caeruleum* + *C. pubescens* treatment. For *B. latifolia*, *M. pudica*, *M. malabathricum*, *P. conjugatum*, *O. nodosa* and *S. sumatrensis* species associations with the cover crop treatments were not consistent over time. These species were associated with some treatments at one date or other. The weed community associated with the un-weeded was distinct from that of all other treatments. It had the highest relative abundance of the grass weeds *A. compressus* and *P. conjugatum* species. *A. gangetica* and *O. nodosa* were also most abundant in the un-weeded plots, albeit at much lower biomass than *A. compressus* and *P. conjugatum* species.

Species Diversity

There was a significant difference between treatments on weed species richness (*S*) (Table 4), but there were no significant changes over time (Table 5). The un-weeded treatment had the highest total number of species (*S* 5.67), followed by *C. caeruleum* + *C. pubescens* (*S* 3.07), *P. javanica* + *C. pubescens* (*S* 2.93), *M. bracteata* (*S* 2.53) and *A. compressus* (*S* 1.27) treatments. The Shannon-Wiener weed diversity index (*H'*) showed significant difference between treatments (Table 4). Weed species diversity decreased over time (Table 5). *A. compressus* showed lower diversity (*H'* 0.20) than others. The diversity was 0.93, 0.77, 0.97 and 1.06 in *C. caeruleum* + *C. pubescens*, *M. bracteata*, *P. javanica* + *C. pubescens* and un-weeded treatments, respectively. There were differences between the sampling dates with respect to mean weed species diversity. The sampling dates were ranked as 18 MAP (*H'* 0.95) > 12 MAP (*H'* 0.84) > 15 MAP (*H'* 0.79) > 9 MAP (*H'* 0.78) > 24 MAP (*H'* 0.57).

Phenolic Compounds in Cover Crop Tissues

Water and acetone extractable phenolics of the cover crop shoots and litter are presented in Fig. 1. The level of water and acetone extractable phenolics in the cover crop shoot

Table 4: Treatment effects on weed species richness (*S*) and diversity (*H'*)

Treatments	Weed species richness (*S*)	Weed species diversity (*H'*)
A. compressus	1.27c	0.20b
C. caeruleum + *C. pubescens*	3.07b	0.93a
M. bracteata	2.53bc	0.77a
P. javanica + *C. pubescens*	2.93b	0.97a
Un-Weeded	5.67a	1.06a

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

Table 5: Weed species richness (*S*) and diversity (*H'*) at different sampling dates

Sampling date	Weed species richness (*S*)	Weed species diversity (*H'*)
9 MAP	3.33a	0.78ab
12 MAP	3.13a	0.84ab
15 MAP	3.27a	0.79ab
18 MAP	3.13a	0.95a
24 MAP	2.60a	0.57b

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 6: Oil palm yield production (September 2011-September 2012)

Treatments	Months after planting cover crop (MAP)					
	12 to 18			18 to 24		
	FFB yield palm^{-1} (kg)	No of bunches palm^{-1} (kg)	Average bunch weight (kg)	FFB yield palm^{-1} (kg)	No of bunches palm^{-1} (kg)	Average bunch weight (kg)
A. compressus	114.3a	16.3a	7.3a	99.1a	10.0ab	9.6ab
C. caeruleum + C. pubescens	108.1a	13.3a	7.1a	66.9ab	8.3ab	8.2ab
M. bracteata	93.4a	12.3a	7.8a	71.5ab	7.3ab	10.8a
P. javanica + C. pubescens	84.9a	9.8a	9.1a	92.6ab	11.7a	7.9ab
Un-Weeded	84.4a	10.5a	8.7a	65.0ab	7.3ab	8.7ab
Weeded	95.5a	10.7a	8.8a	33.1b	4.7b	6.0b

Means within columns followed by the same letter are not significantly different at P = 0.05 according to Tukey's test. FFB= Fresh fruit bunch. MAP= months after planting

was higher than those in the litter. The highest water extractable phenolics in the 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).

Oil Palm Yield

On a per palm basis, the average bunch number and the average bunch weight in palms between 12-18 MAP showed no significant differences (Table 6). However, during the 18-24 MAP there were significant differences in fresh fruit bunch (FFB), bunch number and bunch weight due to treatments. The *A. compressus* treatment had the highest FFB (99.1 kg palm^{-1}) and the weeded treatment had the lowest FFB (33.1 kg palm^{-1}) yield. The FFB yields in the *C. caeruleum + C. pubescens*, *M. bracteata*, *P. javanica + C. pubescens* and un-weeded treatments were 66.9, 71.5, 92.6 and 65 kg palm^{-1}, respectively. *P. javanica + C. pubescens* had the largest number of bunches (11.7), which differed significantly from the weeded treatment with 4.41 bunches. The *A. compressus*, *C. caeruleum + C. pubescens*, *M. bracteata* and weeded treatments had 10, 8.3, 7.3 and 7.3 bunches, respectively and was not significantly different from the *P. javanica + C. pubescens* treatment. The heaviest average bunch was recorded in the *M. bracteata* plots (10.8 kg), while the lightest was recorded in the weeded plots (6 kg). Bunch weight in treatments with *A. compressus*, *C. caeruleum + C. pubescens*, *P. javanica + C. pubescens* and un-weeded were 9.6, 8.2, 7.9 and 8.7 kg, respectively.

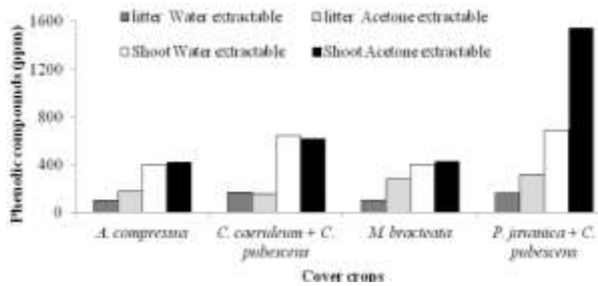

Fig. 1: Water and acetone extractable phenolics in cover crop tissues at 24 months after planting

Discussion

Initial weed vegetation analysis was determined the weed species present, and evaluate their density and dominance pattern in the experimental locality. One of the keys for a successful weed management strategy is the knowledge of weeds in the field, and the density of each species present (Krueger *et al*., 2000). Sorenson's index of similarity between the different blocks ranged from 70 to 88%. Sukarwo (1991) had reiterated that >75% homogeneity is required to conduct weed control experiments. Thus, the experimental field had an acceptable level of homogeneity in terms of weed composition.

The experiment was conducted under a naturally occurring mixed weed population comprising of 12 species. On the basis of summed dominance ratio values, the initial dominance pattern was ranked in the order of: *Borreria latifolia* > *Axonopus compressus* > *Scleria sumatrensis* > *Asystasia gangetica* > *Paspalum conjugatum* > *Ottochloa nodosa* > *Mimosa pudica*. The dominance of *B. latifolia* was evident with a much higher SDR value (60%) than the other species present, followed by *A. compressus* (SDR 11%). Broadleaf weeds constituted more than 76.4% of the initial weed population. In fact, a single predominant weed is rarely found under field conditions, and predominant weeds are usually composed of a few weed species (Aldrich, 1984). The experimental field had been sprayed with glufosinate ammonium herbicide over the last 4 years, and this might have influenced the dominance of weeds with *B. latifolia* (SDR 60%) and *A. compressus* (SDR 11%) as the initial dominant weeds in the experimental site.

A. gangetica was favored by *A. compressus* and *C. caeruleum* + *C. pubescens* based on the significantly higher SDR values compared to the *M. bracteata*, *P. javanica* + *C. pubescens* and un-weeded treatments. *A. gangetica* was present in all treatments at 24 MAP. The *A. compressus* treatment reduced weed diversity. Absence of tillage and the presence of planted cover crops may have reduced germination of weeds from the seed bank, and thus decreased diversity (Senarathne and Perera, 2011). The weed community associated with *M. bracteata* treatment was more similar to that of the *P. javanica* + *C. pubescens* treatment than to the *C. caeruleum* + *C. pubescens* treatment. *M. bracteata* and *P. javanica* + *C. pubescens* treatments were associated with high relative abundance of *A. compressus* and *A. gangetica*. *A. gangetica* is one of the four weed species that is generally accepted as being the most damaging weeds in Asia, including *Ischaemum muticum*, *Imperata cylindrica*, and *Mikania cordata* (Quah *et al.*, 1999). *A. compressus* is considered a soft weed in oil palm plantations (Corley and Tinker, 2003). The effect of cover crops on the weed community and diversity has been reported by several researchers (Kamara *et al.*, 2000; Smith and Alli, 2007; Baumgartner *et al.*, 2008). The unique species-treatment associations clearly demonstrate that cover cropping practices influenced the weed communities. An understanding of the weed community along with dominance patterns is necessary for effective weed management.

For *B. latifolia*, *M. pudica*, *M. malabathricum*, *P. conjugatum*, *O. nodosa* and *S. sumatrensis* species association with cover crop treatments were not consistent over time. These species were associated with some treatments on some dates and with other treatments on another date. It is possible that the variation in biomass of these weeds can be explained, at least in part, by some factor other than cover crops.

The results of the present experiment showed that in weeded treatments, which were sprayed every 4 months with glufosinate-ammonium, *B. latifolia* grew and recovered faster than other weeds, and was followed by *A. compressus*. Even after two years of using herbicides, the weeded treatment had the highest density of *B. latifolia*. The high density of *B. latifolia* in the initial, after four years of spraying, and weeded treatment, after two years of spraying, showed that the glufosinate-ammonium treatment influenced the dominance of this weed. These results confirm the findings of Wibawa *et al*. (2009), who showed that glufosinate-ammonium at 200 to 800 g a.i. ha^{-1} was effective until 14.8 weeks, while the weed composition was changed from grasses to broadleaved weeds. Base on the high relative abundance of *B. latifolia* in the herbicide treated plots during the experiment, it was evident that repeated use of glufosinate-ammonium shifts the oil palm weed community to this species. The presence of a dominant tap root may have enhanced its tolerance to glufosinate-ammonium. *Eleusine indica* has also been reported to be resistant to glufosinate-ammonium (Adam *et al.*, 2010).

Weed composition in the un-weeded treatment was different from that with cover crop treatments. Based on our findings of high relative dominance of *P. conjugatum* and *A. compressus* species in the un-weeded treatment, it is possible that either high competition ability or the absence of herbicides shifted the oil palm weed community to these species. *P. conjugatum* species is considered problematic in oil palm, because of its height that interferes with lose fruit harvest (Turner and Gillbanks, 2003). Initially, *B. latifolia* was the dominant species in the un-weeded plots. It appears that after herbicide spray, pioneer weed species dominated the area. With time weeds that did not tolerate shade was controlled by competition from other species that were fast-growing. Weed populations, especially in crop areas, are never constant. They are in a dynamic state of flux due to changes in climate and environmental conditions, cropping systems, growing season, cultural practices, weed seed bank composition and periodicity of germination patterns of different weed species (Juraimi *et al.*, 2010). The weed floristic composition of a particular site may change over time, as weed communities are a complex ecological entity (Mortimer, 2000).

Existence of phenolic compounds in cover crops tissues was confirmed in the present study. Amount of acetone extractable phenolics was much more relative to the water extractable phenolics. *P. javanica* + *C. pubescens* had a higher phenolic content than other cover crops in the shoot. The allelopathic effects of cover crops have been previously reported (Manidool, 1992; Corley and Tinker, 2003).

The increase in the fresh fruit bunch of *A. compressus* plots compared to *C. caeruleum* + *C. pubescens*, *M. bracteata*, *P. javanica* + *C. pubescens*, un-weeded and weeded plots during 18-24 MAP was about 32, 27, 7, 34 and 66%, respectively. Teoh and Chew (1980) showed that oil palm increased yields in response to covers with legumes, a mixture of natural vegetation with legumes, and naturals with *Mikania*. *Mikania* alone decreased oil palm yields due to competition for soil nutrients. Gray and Hew (1968) showed that in a natural ground cover, the application of compound fertilizer (8% N, 4% P, 14% K and 2% Mg) gave a 13% yield increase in the first 6 years. The same increase in yield could be obtained by establishing a legume cover, and with this, the fertilizer only gave a further 3% increase. Mathews and Saw (2007) showed that the increase in yield of *M. bracteata* plots compared to natural covers was only about 5.6%, which was probably not significant during the 3 years of harvesting. Chiu and Siow (2007) reported that *M. bractata* plots out yielded natural covers by 32 percent (21 t ha^{-1} versus 15.9 t ha^{-1}) in an experiment over 4 years.

The weed treatment had the lowest oil palm yield. The increase in oil palm yields in *M. bracteata* plots compare to weeded was due to the increase in mean bunch weights, while in *A. compressus* and *P. javanica* + *C. pubescens* plots it was due to the slight increase in bunch number. Bare soil results in damage to soils and so ground cover is necessary for several reasons (Corley and Tinker, 2003). Wibawa *et al*. (2007) reported that glufosinate ammonium had no adverse effects on the vegetative and generative growth of oil palm. Therefore, less yields in weeded treatments compared to treatments with ground vegetation may be was due to no vegetation.

The yield advantage of oil palm with cover crops compare to weeded plots show that cover crops unlikely compete with the oil palm stand for the same nutrients. If cultivated cover crops had uniform coverage with a root system that is not especially competitive, do not show intense competition with palms, and are low growing (Turner and Gillbanks, 2003).

Given that oil palm yields was unaffected by the high weed biomass in the un-weeded plots, it seems that weed growth poses a minor threat to oil palm yields. However, treatments associated with the high relative abundance of *P. conjugatum* and *A. compressus* species can be problematic in oil palms, because of the perennial nature and height. The lack of cover crop treatment effects on yield parameter compared to un-weeded plots over the two years also suggests that changes in species composition did not have any impact on production.

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