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Shifting and dominance of weed species following solarization treatment under organic farming system in tropical highland

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Abstract Weed control is essential to improve plant productivity under an organic farming system. This practice often leads to shifting of weed species. The experiment confirmed that two-month solarization treatment brought about the alteration of weed species, but the number of weed species was not significantly different, approximately fifteen species for each treatment. Solarization treatment led to weed shifting and dominance from grass to broadleaf weeds. Red plastic mulch shifted *Blumea lacerna* dominance to *Ricardia brasiliensis* at 0-5 cm depth. Meanwhile, at 10-15 cm soil depth, the dominance of *Eleucine indica* was shifted into *Bidens pilosa*. Mulch treatment substantially reduced the number of weed population to the depth of 15 cm from the soil surface. After two months of solarization, clear plastic mulch is the most effective to reduce weed dry weight. Solarization significantly decreased weed dry weight by approximately 30, 60 and 65 % in treatments using silver black, black, and clear plastic mulch respectively in comparison to the control.

Keywords: Weed shifting; Weed dominance; Organic farming; Solarization, Mulch

Introduction

Weeds become a serious problem in the organic farming system as they may reduce yields in three different ways: through competition, interference with harvest and by harboring pests. To minimize the yield losses due to weeds, considerable interest was recently aroused throughout the world; involving technologies which are ecologically sound and culturally acceptable. The use of polyethylene mulches as weed control was promising both in experimental and commercial basis in some countries. This mulching technology is referred to as solarization. Solarization is a method of soil heating using plastic sheets to retain the sun radiation (Horowitz *et al*., 1983).

The technology becomes an increasingly important concept in the agricultural production systems (Stapleton, 2000). Several numbers of

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researchers have reported that soil solarization is an effective method to control weeds mainly in the area with high light intensities. Either plastic or organic mulch has been reported to increase soil temperature. Soil temperature in soil solarization treatment rises up to 42–55 ^{o}C at a depth of 5 cm and decreasing to 32–37^{o}C at 45 cm depth (Elmore *et al*., 1977). Soil solarization has been reported to suppressed weed growth and expansion of pest and diseases, as well as increased crop yield (Elmore *et al*., 1977; Khan *et al*., 2013; Singh and Kamal, 2012). Clear plastic mulch is more effective than black plastic in reducing seed bank. The soil temperature was raised from 37^{o}C to 49^{o}C in clear plastic while only 30^{o}C to 42^{o}C in black plastic was observed (Sahile *et al*., 2005). Setyowati *et al.* (2017a) reported that clear plastic mulch resulted in the higher soil temperature followed by black and silver black plastic after soil solarization.

The duration of solarization is a factor influencing the effectiveness of the mulching to control weeds. Reduction of weed density and biomass was observed when the period of solarization was increased (Golzardi *et al*., 2014). It was reported that 46 out of 57 weed species were suppressed after 50 days of mulch treatment. Soil solarization for 45 days was reported to suppress weed growth by up to 80% (Bond *et al*., 2003). The effectiveness of soil solarization for weed control is also species-dependent. Linke *et al*. (1991) observed changes in the composition of the weed communities in solarized soil. Most weeds, mainly annual weeds, were well controlled by solarization. Weed cover was 75.7 -84.6% lower after solarization. Also, solarized plots had 82.1% lower weed infestation than non-treated plots.

The depth of soil also affects the susceptibility of weed to soil solarization. Osman *et al.* (1991) reported that the germination, viability, and emergence of *Striga asiatica* seeds were reduced by burying the seed into soil solarized with transparent mulch. However, the mulch enhanced the emergence of *S. asiatica* in field conditions. Peachey *et al.* (2001) reported that solarization reduced *Poa annua* seed survival only in the upper 5 cm of soil but enhancing their survival below the depth. Soil solarization was effective to suppress seed inhibition at the soil depth 0-15 cm (Setyowati *et al*., 2017b).

The objective of the study was to determine weed shifting following solarization treatments in long term tropical highland organic farming system and to find out weed dominance.

Materials and Methods

The experiment was conducted at CAPS (Closed Agriculture Production System) located in Air Duku Village, Sub-district of Selupu Rejang, District of Rejang Lebong, Bengkulu Province, Indonesia. The altitude of the experimental station is 1054 m above sea level. The experimental site was managed as organic agricultural land since 2009.

Initial weed identification

Weed species were identified using the method described by Soerjani *et al.* (1987). The experimental site was assigned and separated into 3 blocks. Weed species at each block was identified and sampled twice in 0.25 m^2 sample plots. The weed species were relatively homogenous based on early results thus the experimental block was separated based on the land slope.

Experimental design and treatments

The experiment was arranged in Randomized Complete Block Design (RCBD) with two factors and replicated three times. Mulch plastic color as the first factor consisted of black, silver black, red, clear and no-mulch as the control treatment. The second factor was soil depth, i.e., 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm. Each treatment combination was replicated three times.

The experimental site was hoed and harrowed then 20 cm high soil beds of 1 m x 2 m in each block were constructed. The experimental plots were separated by 100 cm between blocks and 50 cm within the blocks. The soil bed was covered with plastic mulch for two months for soil solarization. During the soil solarization, soil temperature was measured every day at 9 am, noon and at 3 pm at the depth of 0 – 5 cm, 5-10 cm, 10-15 cm and 15-20 cm. The light intensity and air humidity were also measured. After two months of soil solarization, the plastic mulch was removed. One kg of soil sample at a depth of 0-5 cm, 5-10 cm - 10-15 cm, and 15-20 cm was collected for weed germination and growth tests.

Greenhouse weed growth inhibition experiment

The greenhouse experiment was arranged in a Completely Randomized Design (RCD) with two factors. The first factor was soil from plastic mulch color, i.e., black, silver black, red, clear and control. The second factor was soil depth, i.e.; 0-5 cm, 5-10 cm, 10-15 cm, and 15-20 cm. The treatment combination was replicated three times.

One kg of each solarized soil was put into a germination tray and then randomly placed in a 60 cm high wooden bench. Each tray was watered every day to maintain the soil moisture. After one month, weed growth was observed.

Statistical analysis

Analysis of variance was calculated using SAS version 9.1.3 portable at p <0.05. When there were significant differences, treatment means were separated using Duncan's Multiple Range Test.

Results

There was no significant effect of mulch colors on soil temperature at 0-5 cm soil depth at 9:00 am and at noon. Mulch color, however, had a significant effect on soil temperature at depth 5 cm or higher. In general, clear plastic resulted in higher soil temperature as compared to the others (Table1).

Table 1. Soil temperature at 9 am, noon and 3 pm (^{0}C) under different mulch color and soil depth after 2 months of soil solarization

Mulch color	**Time**	**Soil depth (cm)**			
		0-5	5-10	10-15	15-20
Black		25.27 a	25.13 ab	25.10 b	25.23 b
Red		24.63 a	24.62 bc	25.05 b	25.46 b
Clear	9 am	25.68 a	25.73 a	26.03 a	26.57 a
Silver Black		25.17 a	24.85 bc	23.73 b	24.73 c
Control		25.07 a	24.34 c	23.87 c	23.48 d
Black		26.55 a	26.71 cd	25.96 bc	25.30 b
Red		27.88 a	27.68 ab	26.86 ab	26.39 a
Clear	noon	27.71 a	28.15 a	27.56 a	27.10 a
Silver Black		26.38 a	26.37 d	25.61 c	24.89 b
Control		27.51 a	27.18 abc	26.24 bc	25.26 b
Black		20.96 c	21.79 bc	21.71 b	21.45 c
Red		22.57 ab	23.24 a	22.78 a	22.14 b
Clear	3 pm	21.52 bc	23.02 a	23.31 a	23.08 a
Silver Black		20.44 c	21.25 c	21.17 b	21.00 cd
Control		23.40 a	22.28 ab	21.59 b	20.79 d

Treatment means within the column, followed by the same letter are not significantly different at DMRT 5%.

Plastic mulch treatments reduced the Sum Dominance Ratio (SDR) value of weeds at all soil depths except at the depth of 5-10 cm. Plastic mulch with different colors also shifted weed dominance. Red plastic mulch shifted *Blumea* *lacerna* dominance to *Ricardia brasiliensis* at 0-5 cm depth. It also shifted the dominance of *Eleucine indica* into *Bidens pilosa* at 10-15 cm (Table 2).

Two months of soil solarization with different plastic mulch suppressed weed growth at 0-15 cm soil depth except for black silver mulch. Clear plastic mulch resulted in lower weed population at 20 cm soil depth as compared to the other colors (Table 3).

Table 2. Weed dominance and SDR value under different mulch color and soil depth

Soil depth (cm)	Sum Dominance Ratio				
	Black	Red	Clear	Silver Black	Control
0 – 5	*Bidens pilosa* (23.50)	*Ricardia brasiliensis* (21.60)	*Blumea lacerna* (21.20)	*Digitaria sp.* (21.80)	*Blumea lacerna* (28.89)
5 – 10	*Ageratum conyzoides* (24.60)	*Bidens pilosa* (23.00)	*Eleucine indica* (43.00)	*Bidens pilosa* (15.10)	*Blumea lacerna* (20.1)
10 – 15	*Eleucine indica* (19.00)	*Bidens pilosa* (22.00)	*Eleucine indica* (31.80)	*Ageratum conyzoides* (25.50)	*Eleucine indica* (66,47)
15 – 20	*Ageratum conyzoides* (19.10)	*Croton hirtus* (21.00)	*Bidens pilosa* (45.50)	*Ageratum conyzoides* (29.60)	*Cyperus lylingia* (29.37)

Table 3. Weed population under different mulch color and soil depth

Mulch color	Soil depth (cm)			
	0-5	5-10	10-15	15-20
Black	31.00 b	63.00 b	51.67 b	58.00 a
Red	21.00 b	58.00 b	49.00 b	78.00 a
Clear	30.67 b	53.30 b	25.00 b	47.00 a
Silver Black	31.00 b	114.30 a	106.00 a	67.67 a
Control	94.00 a	168.70 a	111.00 a	69.67 a

Treatment means within the column, followed by the same letter are not significantly different at DMRT 5%.

Table 4. Weed dry weight at different mulch colors and soil depth after two months of soil solarization

Mulch color	Weed dry weight (g)			
	0-5cm	5-10cm	10-15cm	15-20cm
Black	0.90 c	0.76 d	1.31 bc	0.74 d
Red	0.92 c	1.53 c	3.75 a	3.97 a
Clear	0.45 cd	1.47 c	0.83 c	0.83 d
Silver Black	1.85 b	2.21 b	1.68 b	1.51 c
Control	3.35 a	3.87 a	1.64 b	2.32 b

Treatment means within the column, followed by the same letter are not significantly different at DMRT 5%.

Soil solarization for two months using plastic mulch reduced weed dry weight up to the soil depth of 10 cm. The highest weed dry weight resulted from the control treatment (without soil solarization). At soil depth 10 cm or deeper, there were no consistent results of weed dry weight among mulches. However, black and clear plastic mulch consistently resulted in lower weed dry weights compare to that of control treatment at all soil depths (Table 4).

Discussion

In general, clear plastic mulch resulted in a higher soil temperature compared to control or other plastic mulch colors (Table 1). This result indicates that sunlight heat emission can penetrate clear plastic with no light reflection. Sahile *et al*. (2005) reported that clear plastic mulch raised soil temperature higher than black plastic mulch.

The increased temperature in clear plastic mulch was higher compared to other mulch treatments. The highest average temperature increment was 2.23 ^{o}C at a depth of 10-15 cm in the morning; 1.84 ^{o}C at a depth of 15-20 cm at noon and 2.19 ^{o}C at a depth of 15-20 cm in the afternoon. This result was lower in comparison with the other studies. Mulching raised soil temperature by 3-6 ^{o}C (Rajablariani *et al*., 2012); 2.2-3.4 ^{o}C (Singh and Kamal, 2012); 2.21 ^{o}C in vertisol soils (Harsono *et al*., 2009) and 9 ^{o}C in plant roots zone (Diaz-Perez and Batal, 2002) in comparison with the control.

Solarization for two months using plastic mulch reduced weed Sum Dominance Ratio (SDR) at all soil depths. The decrease in SDR value indicates that more weed species are growing in the field. An increasing number of species has a positive ecological effect due to lowered species population. Table 3 shows that the weed population was lower in mulch treatment than control. This result indicates that there is a decline in the soil seed banks. The existence of more weed species means that it will be easier to control them since there will be competition among weed species. The indicators for successful weed control are being able to increase weed species and reduce species population.

Plastic mulching resulted in the shifting of weed species dominance. The dominance of *Blumea lacerna* shifted to *Ricardia brasiliensis* in the red plastic mulch at 0-5 cm soil depth (Table 2). *B. lacerna* and *R. brasiliensis* are not noxious annual weeds in agricultural practices; however, *B. lacerna* seeds are easily dispersed by the wind. Soerjani *et al.* (1987) reported that the spread of *B. lacerna* was through the wind.

At 10-15 cm soil depth, red mulch shifted the dominance of *Eleucine indica* into *Bidens pilosa*. This weed dominance shifting has a positive effect on weed control in the field. *E. indica* is a yearly weed, spreading both generatively and vegetatively while *B. pilosa* is another annual weed, spreading by seed. Weeds spread by the seeds are easier to control compared to that which spreads by both stolons and rhizomes. Soerjani *et al*. (1987) confirmed that *E. indica* was an important weed because it was difficult to control manually.

Table 3 shows that the weed population is lower in the mulch treatment than in the control. This result is closely associated with rising soil temperature either in the morning or in the afternoon (Table 1). Temperature brings about protein denaturation; therefore, weed seeds were not able to germinate due to embryos damage. A similar result was reported by Johnson and Fennimore (2005), where clear plastic mulch suppressed weed growth both in the laboratory and in the field.

Two months soil solarization using black, red, and clear plastic mulches suppressed weed growth to a depth up to 15 cm (Table 3). This result is related to soil temperature. In the 0-15 cm soil depth, the soil has direct contact with the mulch, and the average of soil temperature tends to be higher (Table 1). A similar finding was reported by Diaz-Perez and Cancel (2002). Plastic mulch transmits sunlight to the soil surface and emits back to the air except for infra-red light. The infrared light rises soil surface temperature under plastic mulch. Soil surface temperature reached 38 ^{o}C - 50 ^{o}C at 10-20 cm soil depth (Marquez and Wang, 2014). Increasing temperature in the root area resulted in seed death and inhibited weed growth. Elmore (2012) confirmed that soil solarization reduced weed growth up to 50-95%. Ibarra-Jimenez *et al*. (2011) also concluded that to acquire high temperatures for weed control required 4-6 weeks of soil solarization. Soil solarization of 45 days controlled weeds up to 80% (Bond *et al.*, 2003). In general, this experiment showed soil solarization for 2 months reduced weed growth up to 48 %.

Soil solarization for two months using clear plastic mulch controls weed growth better than the other mulches. Clear plastic suppresses weed growth up to 78, 68, 77 and 32% at 0-5 cm, 5-10 cm, 10-15 cm and 15-20 cm soil depth respectively. Overall, clear plastic mulch inhibits weed growth by 63.75%, whereas black, red and silver suppress weed growth as much as 54, 26 and 47% respectively. In general, clear plastic mulch also resulted in lower weed dry weight (Table 4). This result is associated with the higher soil temperature of clear plastic mulch than other treatments (Table 1). Elmore (2012) and Khan *et al*. (2012) remarked that mulching with clear plastic a few weeks before planting reduced the number of weed seeds and soilborne diseases in strawberry plants.

It was concluded that clear plastic mulch was more effective in controlling weeds than the other treatments. Clear plastic mulch resulted in lower weed population and dry weights compared to that of red, black, silver black plastic mulches and control treatments. Soil solarization also resulted in weed shifting under organic farming systems in the tropical highlands.

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