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Soil Solarization with Colored Plastic Mulched Influenced Weed Growth and Soil Temperature in Tropical Highland

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Soil solarization using plastic mulch is commonly used in organic farming practice to suppress weed growth, increase soil temperature, and maintain soil moisture, leading to enhancement of crop yield. The study aimedto determine the effect of color plastic mulches on the soil temperature and the weed growth in tropical highland. A field experiment was carried out at the CAPS Research Station located in Air Duku Village, RejangLebong, Bengkulu at 1054 m above sea level. The experiment was arranged using Completely Randomized Block Design (RCBD) with treatments of plastic colors, i.e. silver-black, black, clear, and without mulch (control). The treatmentwas replicated 3 times. Plastic mulches were laid on 1m x 2 m raised soil bed for 2 months of soil solarization treatment. Soil temperature was measured everyday in the morning (9.00 am), at noon (12.00 am) and in the afternoon (03.00 pm) for 2 months at the depth of 5, 10, 15 cm from the soil surface. Soil samples at the depths of 0-5 cm, 5-10 cm, and 10-15 cm were collected after 2 months of solarization. Weed seed germination and its growth were tested in the greenhouse. The greenhouse test was conducted using a factorial completely randomized design. The first factor was plastic mulch colors and the second factor was the soil depths. The experiment pointed out that most of weed species were not influenced by soil solarization for 2 months but*Amaranthus gracillis* at depth 5 cm. It was observed that 13 broadleaf weeds, 2 grass species, and a nutsedgewere still able to grow after soil solarization and *Croton hirtus*was the dominant weed. The highest soil temperature was achieved by clear plastic mulch, followed by black and silver black, being control had the lowest temperature.Nonetheless, soil solarization for 2 months using plastic mulch for organic farming practice in a tropical highland has not been effective to control weed since soil temperature for weed inhibition was not achieved.

Keywords: weed control, soil solarization, plastic mulch, soil temperature, tropical highland

Introduction

Weeds always compete with agricultural crops for nutrients, water, sunlight as well as growing space (Anderson, 1983; Monaco *et al*, 2002; Zimdahl, 1993). A yield loss due to weed infestation varies among crops

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depending on their species. As a result of weed invasion, rice yield loss attains 35%; soybean 145%; tomato 67%; corn 862%, even onion reaches 2.355%.Another word, weed control brings about the increase in soybean yield as much as 145% while corn 862% (Naylor, 2002; Zimdahl, 1993). Therefore, it is mandatory to control weeds to eliminate crop yield loss.

Use of synthetic herbicide is avoided in organic framing system. Recently, the particular farming practice have been developed in a number of crop production (Muktamar *et al.*, 2016; Muktamar *et al.*, 2017; Fahrurrozi *et al.*, 2015; Chozin *et al.*, 2017).The use of mulch is believed to be a dependable solution to control weeds for organic farming practice. Various types of mulches have been reported as tools to inhibit weed growth, including hay, straw, sawdust, woodchip, as well as plastic mulch in varying color (Barker, 2010).

Taking advantage of solar radiation is commonly used to suppress weed seed germination and vegetative shoot growth.This cultural method which is called soil solarization is non-chemical weed control by taking benefit of solarenergy to heat up the soil. An increase in soil temperature inhibits weed seed germination and vegetative shoot growth by means of protein denaturation. Plastic mulch installation for 4-5 weeks is able to raise soil temperature up to 40-55^{o}C. The condition will bring about the suppression of weed seed germination and the growth of vegetative organs. The length of mulch installation to obtain effective weed inhibition is heavily dependent on weed species and population, soil condition, climate as well as types of plastic mulches (Rubin and Benjamin, 1984).

Different colors of mulches provide the different impact on the germination of weed seeds. A previous laboratory test revealed that when weed seeds were covered with mulch, their germination was suppressed. Black plastic had higher inhibition of weed germination than clear plastic but was not significantly different from blue, red, brown, yellow, white as well as green plastic covers. Field experiment confirmed that colored plastic mulches had higher capability of weed control than clear one. In addition, yellow, green, brown, white and black plastic mulches were superior to blue or red plastic mulch (Johnson and Fennimore, 2005; Umass Extention, 2012; Sun *et al*, 2015).

In addition to mulch color, intensity and length of solar radiation also highly govern thegermination and growth of weeds. Suppression of weed germination is prominently associated with a riseinsoil temperature but the increment of soil temperature declines at deeper soil profile. Greater suppression will be obtained at longer mulch radiation and higher radiation intensity. Increase in 10^{o}C of soil temperature is able to inhibit most of the weed species; however, some annual weed species and hard skin weed seeds are not easily controlled using the method (Bond *et al.* 2003). Soil solarization for 6 weeks is capable of weed suppression, leading to an increase in crop yield. Weed seed germination is inhibited up to 64-69% with soil solarization for 1-4 weeks (Abu-Irmaileh, 1990; Cohen and Rubin, 2007; Ibarra-Jimenez *et al,* 2011; Marquez and Wang, 2014).

Soil solarization with plastic mulches has been widely used for food and horticultural crops in green house as well in the field. The method has been commonly applied to control weeds in a tropical environment with characteristically high and constant daily temperature. Soil solarization suppresses weed growth and pest development, leading to improvement of crop yield (Elmore *et al*, 1997; Khan *et al*, 2013; Singh and Kamal, 2012). Mulch installation for 4-6 weeks is necessary to gain higher temperature to be able to control weed growth (Elmore *et al*, 1997; Ibarra-Jimenez *et al*, 2011). Plastic mulch will transmit the solar radiation to the soil surface and reradiate them to the atmosphere but infrared. The infrared will brings about the increase in the soil temperature, reaching 38-50^{o}C at the depth of 10-20 cm (Marquez and Wang, 2014).

Different types, colors, and specifications of plastic mulches are currently available in the market (Gill and McSorley, 2011). Previous studies showed that in comparison to the control, aplastic mulch raises soil temperature by 3-6^{0}C (Rajablairani *et al*, 2012); 2.2-3.4^{0}C (Singh and Kamal, 2012); 2.21^{0}C in Vertisol (Harsono *et al,* 2009) and 9^{0}C in the rhizosphere (Diaz-Perez and Batal, 2002). Maximum soil temperature mostly occurs in the afternoon on 13.00 to 14.00.

The objective of the study was to determine the effect of color plastic mulches on the soil temperature and the weed growth in tropical highland.

Materials and Methods

Field Experiment.

The experiment was conducted in April to July 2017 at the Closed Agricultural Production System (CAPS) Research Station situated in Air Duku Village, SelupuRejang Sub-district, District of RejangLebong, Bengkulu, Indonesia at an altitude of 1054 m above sea level. The experimental site was a dry land cultivated with vegetable crops since 2009. The experiment was arranged in Randomized Completely Block Design with 4 treatments, i.e. black, silver black, and clear plastic mulches, as well as control (without mulch), assigning for 2 months of soil solarization. The treatment was replicated 3 times.

The experimental site was handed tilled using a hoe, afterward,soil beds of 1x2 m were constructed in each block. The soil bed was separated 50 cm within the block and 1 m between the block.Soil bed was completely covered with plastic mulch for soil solarization, according to each treatment. Soil temperature was measured daily (morning 09:00 am, noon 12:00 am, afternoon 03:00 pm) for 2 monthsat the depth of 0-5 cm, 5-10 cm, and 10-15 cm. After 2 months, plastic mulch was opened and 2 kg of soil sample at the depth of 0-5 cm, 5-10 cm, and 10-15 cm was collected to evaluate weed growth. Germination and weed growth test was carried out in the green house for a month.

GreenhouseExperiment

Green house test was prepared to determine which plastic color had the highest suppression of weed germination and growth at certain soil depth. The experiment was set in a factorial completely randomized design with 3 replications. The first factor was the soil sample from 2 months solarization with different plastic color, i.e. black, silver-black, clear, and control. The second factor was soil depths, i.e. 0-5cm, 5-10cm, and 10-15cm.Each soil sample was put into germination tray and the tray was randomly laid on 60 cm-high wooden rack. After one month of growing period, weed was harvested, identified, oven-dried, and weighed for dry shoot weight. During the green house test, the soil was kept moist by watering when required.

Statistical Analysis.

Data were subjected to ANOVA at the confidence level of 95% using SAS 9.1.3. The treatment means were separated using Duncan Multiple Ranges Test at $p<0.05$.

Result and Discussion

After 2 months of soil solarization, the number of weeds at each treatment ranged from 8-14 species and mostly was dominated by broadleaf weeds as indicated in Table 1. However, it was also detected grasses such as *Echinochloa colonum*and *Eleusineindica* and nutsedgesuch as *Cyperusrotundus*. Eight to nine species of weeds were found at the depth of 0-5 cm and the number decreased at the deeper part of the soil. In addition, it was discovered 14 weed species at the depth of 10-15 cm when treated with clear plastic mulch. This indicated that certain weed species were sensitive to soil solarization.

Table 1. Existence of weed species under different plastic much color andsoil depth 2 months after soil solarization

Weed species	LF	black			silver black			clear			Control		
		A	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**	**A**	**B**	**C**
Allmanianodiflora	BL	o	√	o	√	o	o	o	√	√	√	√	√
Amaranthus grassilis	BL	o	√	√	o	√	√	o	√	√	√	√	√
Amaranthus spinosus	BL	o	√	√	√	o	√	√	o	√	√	√	o
Bidens pilosa	BL	o	o	o	o	o	o	o	o	o	√	o	√
Croton hirtus	BL	√	√	√	√	√	√	√	√	√	√	√	√
Cyperus rotundus	S	√	√	√	√	√	√	√	√	√	√	√	√
Drymaria violens	BL	√	√	√	√	√	√	√	√	√	√	√	√
Echinochloa colonum	G	√	√	√	o	√	√	√	√	√	o	√	√
Eleusine indica	G	√	√	√	√	√	√	√	√	√	√	√	√
Hedyotis corymbosa	BL	o	√	√	√	√	o	o	√	o	o	√	√
Leucas lavandulifolia	BL	√	√	√	√	√	√	√	√	√	√	√	√
Lindernia anagalis	BL	√	o	o	o	o	o	o	o	√	√	o	o
Lindernia ciliata	BL	√	√	o	o	√	√	o	o	√	o	o	o
Melochia codifolia	BL	√	√	√	o	√	√	√	√	√	o	√	√
Mimosa invisa	BL	o	o	o	√	o	o	o	o	o	o	o	o
Portulaca oleracea	BL	o	o	√	o	√	o	o	o	√	√	√	o
Total		9	12	11	9	11	10	8	10	14	9	12	11

Note:A=0-5cm; B=5-10cm; C=10-15cm; LF= Leaf Figure; BL= Broadleaf; G=Grass; S=Sedge;√=present;o=not present

Broadleaf weed of *Croton hirtus* was dominant at all treatments and soil depths as shown in Table 2. Other than control, the dominance of the weed species at 5-15 cm depth of black plastic mulch treatment was nearly 45%. *C. hirtus*proliferated using seeds. In 1m^2, the species produced 12,381seeds (Gue *et al.,* 2015) and the seed bank was greater in the tilled soil than the untilled one. The experimental site was continuously ploughed each season before planting crops since 2009, bringing about the accumulation of *C. hirtus* seeds in the soil. As a result, when there wasan opportunity to grow, the weed species was more dominant than other species such as *Bidens Pilosa*and *Portulacaoleracea.*

Table 2. Dominance of*C.hirtus*, weed population and weed dry weigh under different plastic much color and soil depth 2 months after soilsolarisation.

Treatment	**Soil depth (cm)**	***C.hirtus* dominance (%)**	**Weed population**	**Weed dry weight (mg)**
Black	0-5	25.5	225 [b]	4.12 [b]
	5-10	44.2	656 [a]	6.55 [a]
	10-15	41.9	623 [a]	6.22 [a]
Silver black	0-5	44.0	361 [b]	2.50 [b]
	5-10	39.8	538 [a]	4.80 [a]
	10-15	43.1	508 [a]	5.76 [a]
Clear	0-5	35.1	198 [c]	3.10 [b]
	5-10	39.7	232 [b]	4.84 [a]
	10-15	37.9	525 [a]	7.08 [a]
Control	0-5	25.9	192 [c]	2.03 [b]
	5-10	44.9	350 [b]	4.57 [a]
	10-15	47.3	562 [a]	4.30 [a]

Number at the same coloumn and treatment at different soil depth followed by the same letter were not significantly different

The weed dominance is highly associated with the population and weed dry weight (Table 2). The lowest population and weed dry weight for all treatments were observed at the 0-5 cm depth. This confirmed from Table 1 that the number of weed species grown near soil surface was fewer than those of further deeper of the soil profile. This indicated that certain weed species such as *Allmanianodiflora, Amaranthusgrassilis*and*Amaranthusspinosus* were inhibited due to soil solarization (Table 1).

The inhibition of weed growth was related to an increase in temperature as a result of soil solarization for 2 months using plastic mulches. Increase in soil temperature at black, silver-black and clear plastic mulches was 6.5%, 5.3%, and 14.1%, as compared to that of control, respectively (Figure 1). The previous study carried out by Abdel-Rahim *et al.* (1988)found out that particular weed species were sensitive to temperature changes. During the course of the experiment, the average of daily soil temperature at all soil depths ranged from 25-30^{o}C.

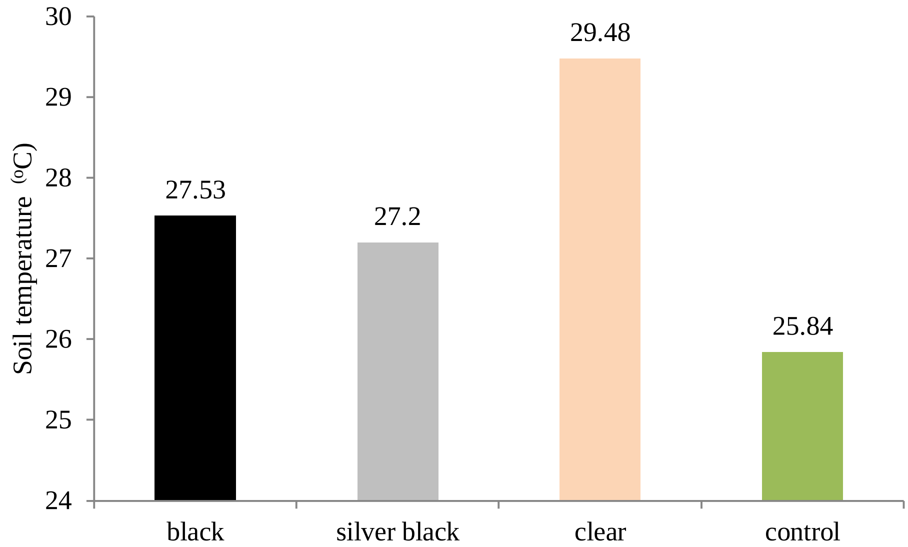

Figure 1. Soil temperature as affected by different plastic color mulches

In addition, the highest increase in soil temperature was observed at clear plastic mulch in comparison to those of black and silver-black ones. Table 4 indicated that clear plastic mulch had a number of days with soil temperature ≥30^{0}Cmore than those of other treatments. However, even though soil solarization with plastic mulches raised soil temperature, the increment did not attain the temperature to suppress weed growth. In this experiment, the highest soil temperature (48^{0}C) had been reached by clear plastic mulch, but the average of soil temperature below 30^{o}C was not able to inhibit seeds and the growth of vegetative weed organs in tropical highland.

Tabel 4. Number of days when soil temperature was ≥20, 25, 30, or 35^{0}C during the solarization period at three soil depths and three color plastic mulch

Treatment	5 cm				10 cm				15 cm			
	≥20	≥25	≥30	≥35	≥20	≥25	≥30	≥35	≥20	≥25	≥30	≥35
Black	1	54	7	0	1	53	8	0	1	55	6	0
Silver black	4	55	4	0	4	55	4	0	3	56	4	0
Clear	1	36	22	3	1	31	28	3	1	27	33	3
Bare soil	7	54	1	0	9	53	0	0	11	51	0	0

According to Buhler and Hoffman (1999)clear mulch increased soil temperature higher than blue, brown, green, yellow, black and silver-black. Clear mulch could inhibit weed germination of common chickweed and spurry sp., which were sensitive to warm condition under mulch during the germination process. Similar findings were found in the experiment where seeds of *A. gracillis* at the depth of 0-5 cm were suppressed by solarization of black, silver-black as well as clear mulches. This might be due to that clear plastic mulch withstood radiant energy to generate greenhouse effect more efficient than other mulches.

The previous study by Abdel-Rahim *et al.* (1988) and Johnson and Fennimore (2005) also confirmed that soil solarization was able to control weeds suchas *Amaranthus* sp. but not *C. rotundus*. Another finding reported by Stapleton and DeVoy (1986) revealed that summer weeds such as *Cyperus* sp. and *Convolvulus arvensis* were more resistant to soil solarization. Kapoor (2013) also found out that perennial weeds were more resistant to soil solarization than annual weeds since the former possessed vegetative organs stored at a lower part of the soil profile and germinated after soil solarization process. Besides temperature, the susceptibility of weed seed on solarization was also affected by soil types, soil moisture content, size and position of seed in the soil during soil solarization treatment.

The result of an experiment reported by Candidio *et al.* (2008) consistently showed that solarization increased soil temperature but as going down to deeper soil profile, the lower temperature was observed. Soil temperature as result of solarization was always greater than that of bare soil. At the depth of 5 cm, average soil temperature was 41.9^{o}C and 37.8^{o}C while at 20cm depth was 39.9^{o}C and 3.6^{o}C for solarized and non-solarized soil, respectively. Soil solarization raised soil temperature up to 59^{o}C and inhibited the growth of most weeds, but at the end of the experiment, *C rotundus* was still able to grow. A similar finding was observed in this experiment where soil solarization consistently increased soil temperature but not all weed species were suppressed. Black, silver-black, and clear plastic mulches increased soil temperatures by 1.7^{o}C, 1.4^{o}C, and 3.6^{o}C, respectively in comparison to that of control with the soil temperature of 25.8^{o}C. Maximum soil temperature was reached 48^{o}C on clear plastic mulch but the soil temperature was not able to entirely control the weeds.

Marenco and Lustosa (2000) claimed that soil solarization raised soil temperature up to 10^{o}C at the depth of 5 cm as compared to that without solarization. After solarization, 20 weeds species was still identified. Likewise, soil solarization reduced biomass and weed density but 40% of weeds was not influenced by mulching. Our finding confirmed that soil solarization in highland organic farming increased soil temperature to 27^{o}C-30^{o}C where most weeds were still able to grow. Only did certain sensitive weed species such as *A. grassilis* from the depth of 0-5 cm not grow after soil solarization. Other weeds such as *C. hirtus, C.rotundus*, *Drymariaviolens*, *E.indica,* and

Leucaslavandulifolia, were still able to grow. Those particular weed species were partly noxious weeds and produced a large number of seeds (Table 1).

Conclusion

Two months of soil solarization was effective to control *A. gracillis* at depth 0-5 cm but most of the weed species, nearly 85% of weed community, were not affected by soil solarization. Thirteen broadleaf weeds, 2 grass species, and a nutsedge were still able to grow after soil solarization and *C. hirtus*was the dominant weed. Greatest average soil temperature was 29.48^{o}C attained by clear mulch, followed by black, 27.53^{o}C and silver-black mulch 27.20^{o}C while soil temperature of un-solarized soil was 25.84^{o}C. Even though, 2 months of soil solartization raised soil temperature, the temperature for weed seed suppression was not attained. Therefore, soil solarization is not an effective method to control weed for organic farming practice in the tropical highland.

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