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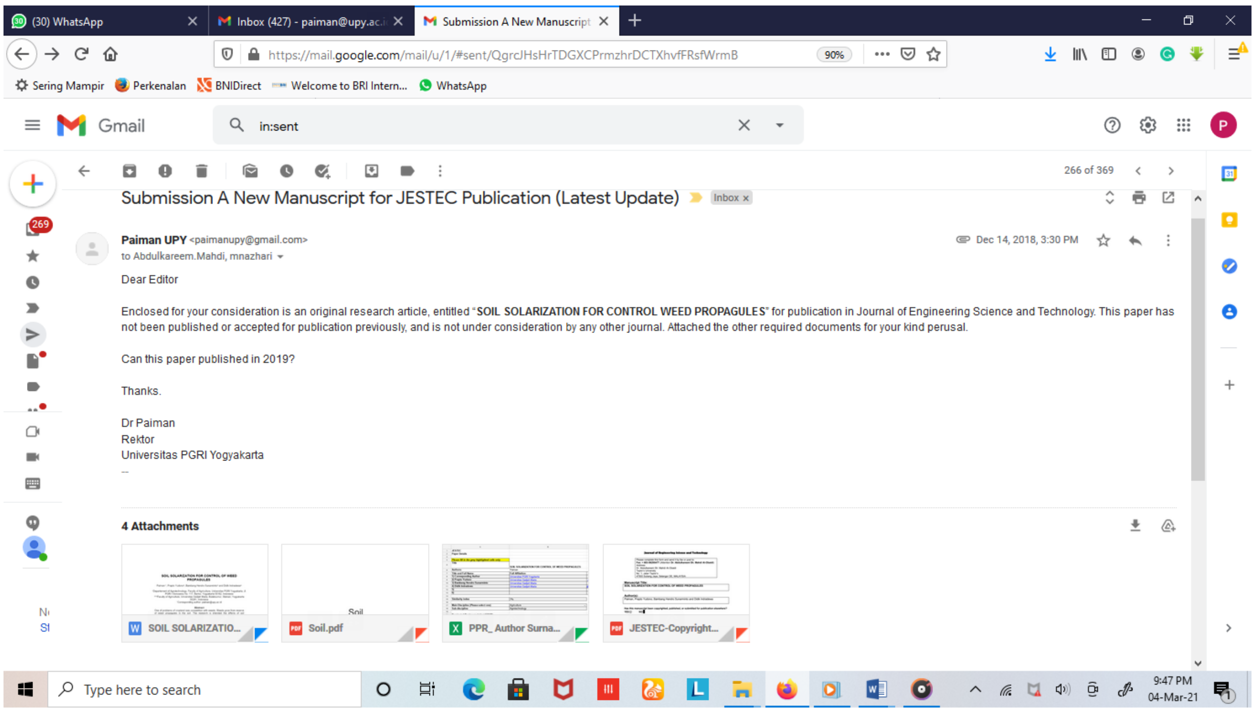

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SOIL SOLARIZATION FOR CONTROL OF WEED PROPAGULES

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Abstract

One of problems of cropland was competition with weeds. Weeds grow from reserve of weed propagules in the soil. The research is intended the effects of soil solarization on weed propagules in the soil. The research was started with a survey to select land overgrown by homogenous of weed species. The research consisted of two factors and arranged in the randomized complete block design (RCBD), replicated three times. The first factor was colored polyethylene (PE) sheets, which consisted of three levels: black, red and transparent. The second factor was duration of soil solarization, which consisted of three levels: 10; 20; and 30 days. One treatment was no solarization as control. The results of the research showed that soil solarization was able to reduce weed propagules in the soil depth. The effect of soil solarization would be more effectively reduce the greatest weed propagules up to soil depth of 9-12 cm. Soil solarization for 30 days were more frequently identified the greater number of days that high soil temperature. The using transparent PE sheets and soil solarization for 30 days are more effectively reduce 77.8% of weed propagules in the soil depth of 0-3 cm.

Keywords: soil solarization, control, weed propagules

1. Introduction

A single weed in one of life cycle can produce the amount of propagule and dispersal drop to the soil around, and many of these seeds may germinate, while others remain dormant for extended period of time. Weed seed usually infest the soil of cropland in the amount of million per acre [1]. Dormancy is an internal condition of the seed that impedes its germination under otherwise adequate hydric, thermal and gaseous conditions [2]. Some weed seeds are buried deeply in the soil, while others lie on the surface or in the litter layer just above the soil surface. In pastures, some 64-99.6% of all weed seeds were found in the upper 4 inch layer of soil, with greater numbers in the 1 to 4 inch layer than in the surface to 1 inch layer [1]. Types of propagules were in forms of the seed, rhizome, stolon, tuber and bulb.

Abbreviations

AM : Ante Meridiem
ANOVA : Analysis of Variance
DMRT : Duncan's New Multiple Range Test
FC : Foot Candle
PE : Polyethylene
RCBD : Randomized Complete Block Design

Weeds seed remain viable for varying periods of time, depending on species involved, when buried in soil or stored in flowing fresh water. Weed seeds remain in viable but dormant condition for many years until conditions favor germination [1]. The seed or vegetative part has a period of metabolic quiescence usually termed dormancy after it is produced. When in this state, the seed or vegetative part does not resume growth, even though all environmental conditions seem to be pavorable [3]. Soil tillage can cause weed propagules germination. Before germination, weed propagules would able to control with soil solarization.

Soil solarization is a hydrothermal process that utilizes the sun's enegy to heat moist soil that is mulched under PE sheets. The basic concept of soil solarization is to use clear plastic films to allow transmission of light energy to the soil, where it is absorbed and used to heat the soil. The clear plastic film decreases convective heat loss so that increased soil temperatures are achived. If the temperature under the plastic film and in the soil reaches sufficiently high temperatures, weed and other pant pests are damaged or killed [4]. Soil solarization is a special mulching technique in which moist soil is covered by PE films and heated by solar radiation for several weeks [5].

Soil solarization, a method of chemical-free pest treatment, is a practical and cost-effective way to treat organic farming soil. This method uses polyethylene sheets to capture solar radiation that heats the soil [6]. Soil solarization with transparan PE sheets can increase soil temperatur up to 52 ºC, but no mulched only 36 ºC. Soil heating was influence by soil depth. The higher soil temperature was in soil depth of 5 cm than soil depth of 10 cm [7]. Soil solarization can increase soil temperature in soil depth of 5 and 10 cm were 50.6 and 47.9 ºC than no solarization were 37.0 and 34.9 ºC [8]. Soil solarization can increase soil temperature of 11; 8; 7; dan 5 ºC than no solarization in soil depth of 5; 10; 20; and 30 cm [9]. Soil solarization in soil depth of 5 and 15 cm can produce soil temperature of 10.6 and 6.6 ºC higher than no solarization [10].

The high soil temperature can decrease dormant period of weed propagules or induce to become scundair dormancy. The long time of solarization can eradicate weed propagules [11]. The soil temperature was much higher than the optimum temperature of germination, there would be damage in enzyme. The effect of soil temperature on weed varied depending long time of solarization, soil depth and weed species. A temperature 50 ºC above at 5 cm was recorded for 31 (years of 2005) and 51 (years of 2006) days in solarized but for 7 (years of 2005) and 18 (years of 2006) days in nonsolarized soil 12]. Soil solarization for 32 days are the best treatment and can decrease 79% of weed propagules germination than without solarization [10]. Soil solarization for 60 days can decease 86% of *Cyperus rotundus* growth in carrot cultivation [8]. Because it, soil solarization is the best solution of pre-emergent weed control. This experiment was conducted to choose the suitable colored PE sheets and the most effective duration of soil solarization for suppress weed propagules in various of soil depths.

2. Materials and Methods

The research was conducted in Sleman, Yogyakarta. The research was started by surveying for selecting land overgrown by homogenous weed species. If the obtained community coefficient ≥ 75% [13], the means both weed communities uniform, thus the research can be conducted on this land.

The materials used colored PE sheets of black, red and transparent with 120 cm width and 25 µ thickness, soil samples, cardboard dos and weeds. Tools used are ruler, tub plastic germination, knives, sprayer, digital scales, soil thermometer and light meter.

The research consisted of two factors and arranged in the randomized complete block design, replicated three times. The first factor was colored PE sheets, which consisted of three levels: black; red and transparent. The second factor was duration of soil solarization, which consisted of three levels: 10; 20; and 30 days. One treatment was no solarization as control. The research used 30 plots treatment.

Light transmittance of colored PE sheets was done an unshaded place. Light transmission was measured from transmitted light was divided incoming light times 100% and repeated 20 times in a day by light meter.

The size of plots were made of 2 m length, 1 m width and 0.2 m height and directed horizontal from east to west and distance both plots treatment were 0.5 m. Plots treatment were covered with colored PE sheets for duration of 30; 20; and 10 days soil solarization. Watering on both plots were to keep the soil moisture. According to [14] moisture content analysis was carried out by gravimetric method.

Light intensity was conducted in 1.5 m above of the plots treatment and repeated three times at 13.00 AM within 30 days. Soil temperatures were measured at soil depths of 0-3; 3-6; 6-9; and 9-12 cm at 14.00 AM with soil thermometer. Soil solarization treatment lasted together.

After soil solarization finished, the colored PE sheets were removed. Then soil samples taken from 25 x 30 x 3 cm (width, length and depth) plots sample or 0.00225 m^3 from soil depth of 0-3; 3-6; 6-9; and 9-12 cm from 30 plots treatment and replicated three times so there were 120 soil samples. The drying soil samples were conducted within 4 days and each soil sample was give a label. After this, then each soil sample was placed into a tub plastics germination with size of 25 x 30 x 5 cm (width, length and high). Watering is applied in a tub plastic germination to keep the soil moisture. A few days later of weed propagules would germinate. After 42 days, weed propagules grew and observable. The number of weed could calculated.

After colored PE sheets were removed from plots treatment, thus weed propagules resistant would grow. And then 42 days from germinate, weeds were observed from plots sample of 50 x 50 cm (width and length) or 0.25 m^2. Then the number of weed could calculated. The number of weeds grows as illustration of weed propagules germinate.

The data of soil temperature and weed propagules were analyzed using Analysis of Variance (ANOVA) at the 5% significant levels [15]. To know the difference both the treatment carried out with Duncan's New Multiple Range Test (DMRT) at 5% significant levels.

3. Results and Discussion

3.1. Light transmittance

Pre-emergent weed control can conduct with various methods. One of them is physical method that utilizes the solar energy by using PE sheets to allow transmission of light energy to the soil. The colored PE sheets determinated light transmittance. The results of observation showed that PE sheets of transparent and red were able to transmitted light, whereas black is not. It can be seen in Table 1.

Base on Table 1 can explained that tranparent PE sheets have high capacity to transmitte the light and followed by red PE sheets. Transparent and red PE sheets have translucent properties, showing that most of the sunlight intensity on the upper surface of the PE sheets were able to pass on to the bottom surface. But of the black PE sheets was not able to pass on the light intensity. According to [5], reported that transparent PE films are recommended for soil solarization because of its high transmittance of short wave (0.3 - 3 µm) radiation, and its low transmittance of long wave (4 - 40 µm) radiation.

Table 1. The light transmitted (%) by colored PE sheets

Parameter	Colored PE sheets		
	Red	Black	Transparent
Light transmitted (%)	67.4 b	0 c	93.5 a

Remarks: Number in the same row followed by the same characters are not significantly different based on t test at 5% significant levels.

3.2. Sunlight intensity

The sunlight intensity was measured by light meter at Foot Candle (FC) in 1.5 m soil above. The sunlight intensity can be seen in Table 2.

Table 2 showed that average of sunlight intensity at the observation number of 1 to 10 were recorded lower (4,848 FC) than at the observation number of 11 to 20 (7,680.3 FC) and 21 to 30 (8,087.3 FC). The high of sunlight intensity only occurred a few days from the observation because of the time of the research coincided with the rainy season. Especially, at the observation number of 1 to 10, the sunlight intensity in the atmosphere disturbed by clouds, so incoming light to earth were low. The success of soil solarization depends on the sunlight intensity to the earth, because it's correlated with the soil temperatures.

Table 2. The sunlight intensity (FC) in 1.5 m soil above

The observation number	Light intensity (FC)	The observation number	Light intensity (FC)	The observation number	Light intensity (FC)
1	3,333.3	11	6,033.3	21	9,853.3

2	3,673.3	12	6,996.7	22	10,830.0
3	8,023.3	13	7,336.7	23	9,646.7
4	4,740.0	14	11,483.3	23	8,863.3
5	5,473.3	15	2,880.0	25	7,820.0
6	4,316.7	16	10,320.0	26	1,883.3
7	7,813.3	17	9,913.3	27	9,886.7
8	2,356.7	18	10,880.0	28	9,710.0
9	6,263.3	19	1,703.3	29	8,850.0
10	2,496.7	20	11,056.7	30	3,530.0
Average	4,848.9		7,860.3		8,087.3

Remarks: The observations were conducted within 30 days

3.3. Soil physical properties

The soil type for experiment was Inceptisol. The analysis of soil physical properties can be seen in Table 3. Base on Table 3 showed that the soil type for experiment including in soil texture of sandy loam. The soil was dominated by sand (73.00%). Soil porosity including the moderate (31.55%).

Table 3. The analysis of soil physical properties

Soil variable	Unit	Value	Soil character
Texture			
○ Sand	%	73.00	Sandy loam
○ Silt	%	21.03	
○ Clay	%	5.97	
Bulk Density	g/cm^3	1.45	
Particle density	g/cm^3	2.14	
Porosity	%	31.55	

3.4. Soil temperature

Soil solarization can produce maximum soil temperatures if soil moisture is maintained properly. Soil moisture during the experiment is around 80 to 90% field capacity. The analysis of variance on soil temperatures showed that there were significant between soil solarization and no solarization in the soil depths of 0-3; 3-6; 6-9; and 9-12 cm. No significant interaction between colored PE sheets and duration of soil solarization on soil temperature in soil depth. The Average of soil temperatures on various of soil depths can be seen in Table 4.

Base on the Table 4 showed that soil solarization treatment caused higher soil temperature compared no solarization in various of soil depths. Soil solarization with using the red and transparent PE sheets were able to make higher soil temperatures and significant different than the black in all of soil depth. In the soil deeply, the effect of colored PE sheets trends decline. According to [16], reported that clear PE sheets was found slightly more effectively than black one in transfering solar radiation to the soil.

Soil solarization for 30 days were given average of soil temperature lower than at 20 and 10 days soil solarization, because at early observation of the light intensity was very low at the days observation of 1 to 10 (Table 2). Soil temperatures were effected by light intensity in atmosphere. If light intensity in atmosphere was low, so the effect on soil temperatures low to. The effect of duration of soil solarization trends decline in soil deeply.

Table 4. The average of soil temperature (ºC) in various of soil depths (cm)

Treatment	Soil depths (cm)			
	0-3	3-6	6-9	9-12
Orthogonal contras				

Treatment	47.0 x	45.0 x	42.6 x	40.5 x
No solarization	35.9 y	34.8 y	33.7 y	32.4 y
Colored PE sheets				
Black	43.8 b	42.3 b	40.6 b	38.6 b
Red	48.5 a	46.3 a	43.6 a	41.3 a
Transparent	48.7 a	46.4 a	43.8 a	41.7 a
Duration of soil solarization (days)				
10	47.8 p	45.7 p	43.2 p	41.2 p
20	47.7 p	45.7 p	43.0 p	40.8 p
30	45.6 q	43.7 q	41.5 q	39.5 q
Interaction	(-)	(-)	(-)	(-)

Remarks: Number in the same column followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

3.5. Mechanism of soil solarization

Soil temperatures are results from all combination magnitude radiation and heat flow in soil. The red, black and transparent PE sheets were able to make higher soil temperatures than no solarization in various of soil depths. The PE sheets decreases convective heat loss so that increased soil temperatures are achived, so heat energy balance can depend in soil surface. Soil temperatures can reach a maximum in plots treatment covered with PE sheets. Incoming solar radiation to penetrate the PE sheets are forwarded to the soil surface, then radiation energy is converted into heat energy. Heat energy through the soil surface conductes to the soil depth more deeply. Mechanism of soil solarization in the soil depth can be seen in Fig. 1.

Fig. 1 could explain that solar radiation is emitted to the earth in form of short wave energy and passes transparent PE sheets in the soil surface, thus until soil surface was changed to heat energy and absorbed by soil that causes to increase the soil temperatures. The process of heart displacement in the soil is conduction. The heat displacement in the soil have occurred from layers to layers in soil depth. Heat received in the soil surface transferred to the soil more deeper. Heat transferred take some time. Fluctuations of temperature the soil depth will high on the soil surface and getting smaller with increasing the soil depth. The maximum temperature on the soil surface will be achieved at the time of intensity of solar radiation reach a maximum. But in the soil more deeper, then maximum temperature is achievable in some time later. Heat is transferred from the soil surface into soil depth will have an effect on weed propagules.

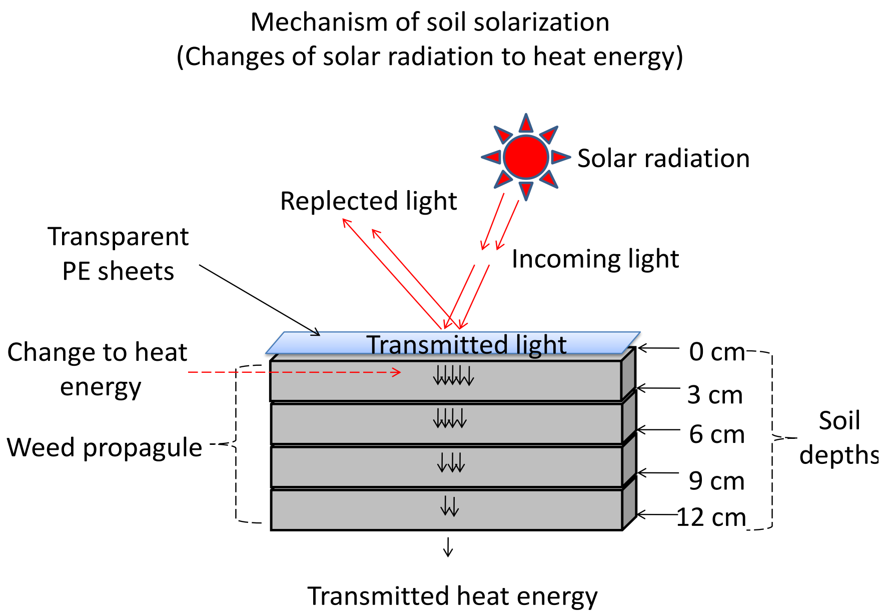

Fig. 1. Mechanism of soil solarization in the soil depths

3.6. Maximum Soil temperature

Base on daily measurement of soil temperature could make interval of soil temperatures. Interval of soil temperature can be seen Table 5. Table 5 showed that in plots no solarization never happens the soil temperature of 50 ºC above during observation. Soil temperatures of 50 ºC above recorded more happen by using transparent and red PE sheets, whereas the by using black PE sheets were less happen.

In soil depth of 0-3 cm, the soil temperature of 50 ºC above is more happens than in soil depth of 3-6 cm. The days that soil temperature 50 ºC above on plots treatment depends on colored PE sheets and acceptance of the amount of heat that can be forwarded. Transparent and red PE sheets is causing the soil temperatures of 50 ºC above were occur more frequently during the experiment than in black. Soil temperatures of 50 ºC above only occur in soil depth of 0-3 and 3-6 cm, whereas in the soil more deeply does not occur. According to [17], reported that temperatures of 50 ºC above were lethal for weed of all species.

Soil temperature provided effects on weed propagules germination. Weed propagules required special temperature for their germination i.e. optimum temperature. The optimum temperature of the seed enzyme varied depending on individual type of weed propagules. The higher soil temperature causes the greater enzyme activity within weed seeds.

The heat generated due to the increased soil temperatures was able to accelerate chemical reaction in weed seeds; hence, the frequency and speed of molecular collisions increased. When the soil temperature was much higher than the optimum temperature, there would be change in enzymatic structure (denaturation); hence, the active part would be interrupted and the reaction rate decreased. The denatured enzyme would lose its catalytic ability. Higher soil temperature would inhibit germination of weed seeds, as it would effect enzymatic action. The amylase enzyme would optimally work at normal temperature and its activity would decrease with the deviation from normal temperature. The activity of amylase enzyme would be disrupted in breaking down starch into sugar when in high soil temperature.

Table 5.The number of days base on interval of soil temperatures in soil depth of 0-3 and 3-6 cm.

Colored PE sheets	Duration of soil solarization (days)	Interval of soil temperatures (°C)				
		< 36	36-40	41-45	46-50	> 50 *)
		At soil depth of 0-3 cm				
No solarization	30	12.4	14.7	2.7	0.0	0.0
Black	10	0.0	2.0	4.0	4.0	0.0
	20	0.0	4.0	6.7	8.3	1.0
	30	2.0	7.0	13.3	6.0	1.7
Red	10	0.0	1.0	0.3	5.0	3.7
	20	0.0	1.3	2.3	7.7	8.7
	30	1.0	4.3	4.7	10.0	10.0
Transparent	10	0.0	0.0	0.7	4.3	5.0
	20	0.0	0.7	3.0	7.0	9.3
	30	1.0	3.7	6.0	9.0	10.3
		At soil depth of 3-6 cm				
No solarization	30	18.0	11.0	1.0	0.0	0.0
Black	10	0.0	2.4	6.3	1.3	0.0
	20	0.0	3.7	12.6	3.7	0.0
	30	3.3	8.0	13.3	4.7	0.7
Red	10	0.0	0.6	1.7	6.0	1.7
	20	0.0	2.4	3.3	12.0	2.3
	30	2.0	3.7	8.6	12.7	3.0
Transparent	10	0.0	0.0	2.4	6.3	1.3
	20	0.0	1.3	6.0	8.7	4.0
	30	2.3	4.7	7.7	11.3	4.0

Remarks: *) Soil temperatures of 50 °C and above is happens only in soil depths of 0-3 and 3-6 cm

3.7. Weed propagules in soil depth

The analysis of variance on number of weed propagules resistant in soil depth after soil solarization showed that there was significant difference between soil solarization and no solarization. No significant different interaction between the colored PE sheets and duration of soil solarization on number of weed propagules resistant in soil depth. The number of weed propagules resistant in of soil depth after soil solarization can be seen in Table 6.

Table 6 showed that soil solarization can suppress weed propagules in various of soil depth. By reducing the light transmittance, the colored mulches were able to resistant the growth of weeds despite their heavy infestation, while the clear mulch had weaker suppression of weed [18]. The types of weed propagules were observed in forms of the seed, rhizome, stolon and tuber.

The use of transparent PE sheets can suppress weed propagules more high than red and black in soil depths of 0-3 cm (74.4; 67.9; and 50.1%, respectively). In the soil depths of 3-6 and 6-9 cm, transparent PE sheets can reduce weed propagules than black and not significant with red PE sheet. Soil solarization using transparent PE sheets are more effectively suppress weed propagules up to soil depth of 9-12 cm than black and red PE sheets.

Soil solarization for 30 days in soil depth of 0-3 cm causes the weed propagules resistant lower than for 10 and 20 days (24.4; 36.2; and 48.7%, respectively). Some weed propagules death in soil depths of

0-3 and 3-6 cm, except four weed propagules species namely *Cleome viscosa, Ludwigia peruviana, Phyllanthus urinaria* and *Physalis angulata.* According to [12], reported that soil solarization with clear PE sheets killed about 95% of buried viable seed, and induced secondary dormancy in the remaining 5%. In the soil deeply, indicated that the effect of colored PE sheets and duration of soil solarization decreases.

Soil temperature in the soil depths of 0-3 and 3-6 cm effectively suppress the weed propagules. High soil temperature caused some weed propagules to undergo metabolic disorder, i.e. the structural damage of enzyme and then weed propagules did not germinate. In the soil depths of 6-9 and 9-12 cm indicated that death weed propagules was less because the effect of soil temperature is getting lower.

Tabel 6. Weed propagules resistant (%) in various of soil depths per 25 x 30 x 30 cm plots sample.

Treatment	Soil depths (cm)			
	0-3	3-6	6-9	9-12
Orthogonal contras				
Treatment	37.0 y	64.7 y	79.1 y	86.2 y
No solarization	100.0 x	100.0 x	100.0 x	100.0 x
Colored PE sheets				
Black	49.9 a	78.9 a	84.4 a	92.4 a
Red	32.1 b	64.5 ab	80.7 ab	87.5 a
Transparent	25.6 b	54.7 b	72.4 b	78.5 b
Duration of soil solarization (days)				
10	48.7 p	78.8 p	91.5 p	92.8 p
20	36.2 q	64.0 q	78.2 q	83.8 q
30	24.4 r	55.4 q	67.7 q	76.7 q
Interaction	(-)	(-)	(-)	(-)

Remarks: Number in the same column followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

3.8. Weed propagules in plots

The analysis of variance on weed propagules resistant in plots showed there were significant difference between soil solarization and no solarization. No significant different interaction between the colored PE sheets and duration of soil solarization on weed propagules resistant in plots treatment. Weed propagules grows in plots can be seen in Table 7.

Base on Table 7 can explained that soil solarization able to reduce weed propagules. Transparent PE sheets could reduce weed propagules more high and significant different than black and red. Soil solarization using transparent PE sheets are more effectively reduce weed propagules in plots. Soil solarization for 30 days can reduce the highest weed propagules and significant different than for 20 and 10 days.

Weed species resistant in all of plots were covered with transparent PE sheets: *Cleome viscosa, Cyperus rotundus, Alternanthera philoxeroides,* and *Cynodon dactylon.* Using of Transparent PE sheets and soil solarization for 30 days can reduce 77.8% of weed propagules. According to [5], reported that solarization reduced weed biomass and density in about 50% of weed species.

Tabel 7. Weed propagules resistant (%) in plots treatment per 50 x 50 cm square plots sample

Colored PE sheets	Duration of soil solarization (days)			Average
	10	20	30	

Black	75.2	62.3	51.9	63.1 a
Red	52.9	35.7	26.8	38.5 b
Transparent	45.0	31.6	22.2	33.1 c
Average	57.7 p	43.2 q	33.8 r	(-)
Treatment				44.9 y
No solarization				100.0 x

Remarks: Number in the same column or row followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

4. Conclusions

The research of soil solarization was able to reduce weed propagules in soil depth. Some concluding observation from this research are given below.

- The effect of soil solarization would be more effectively reduce the greatest weed propagules up to soil dept of 9-12 cm.
- Soil solarization for 30 days were more frequently identified the greater number of days that high soil temperature.
- The using transparent PE sheets and soil solarization for 30 days are more effectively reduce 77.8% of the weed propagules in soil depth of 0-3 cm.

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Submission A New Manuscript for JESTEC Publication (Latest Update)

Paiman UPY <paimanupy@gmail.com>　　Fri, Dec 14, 2018 at 3:30 PM
To: Abdulkareem.Mahdi@taylors.edu.my
Cc: mnazhari@ftv.upsi.edu.my

Dear Editor

Enclosed for your consideration is an original research article, entitled "**SOIL SOLARIZATION FOR CONTROL WEED PROPAGULES**" for publication in Journal of Engineering Science and Technology. This paper has not been published or accepted for publication previously, and is not under consideration by any other journal. Attached the other required documents for your kind perusal.

Can this paper published in 2019?

Thanks.

Dr Paiman
Rektor
Universitas PGRI Yogyakarta
--

4 attachments

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To: Paiman UPY <paimanupy@gmail.com>
Cc: "mnazhari@ftv.upsi.edu.my" <mnazhari@ftv.upsi.edu.my>

Dear Author

Thank you for your email
We will check the submission and send you an email with some details within two weeks from the date of your email.

Best regards

Associate Professor Dr. Abdulkareem Sh. Mahdi Al-Obaidi, CEng MIMechE
Executive Editor, Journal of Engineering Science & Technology
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2. Revised by Editor

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Abdulkareem Shafiq Mahdi Al-Obaidi <Abdulkareem.Mahdi@taylors.edu.my>   Mon, Feb 11, 2019 at 6:09 PM
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Paiman UPY <paimanupy@gmail.com> Wed, Feb 13, 2019 at 4:00 PM
To: Abdulkareem Shafiq Mahdi Al-Obaidi <Abdulkareem.Mahdi@taylors.edu.my>
Cc: Mohamed Nor Azhari bin Azman <mnazhari@ftv.upsi.edu.my>

Dear Sir,

Herewith I attach the revised article. I have already revised the article based on the formatting reference and JESTEC Template.
Thank you.

Best regards,
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To: Paiman UPY <paimanupy@gmail.com>

I have to resend again

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Abdulkareem

From: Abdulkareem Shafiq Mahdi Al-Obaidi
Sent: Monday, February 11, 2019 7:09 PM
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Paiman UPY <paimanupy@gmail.com> Tue, Mar 19, 2019 at 3:50 PM
To: Abdulkareem Shafiq Mahdi Al-Obaidi <Abdulkareem.Mahdi@taylors.edu.my>
Cc: Mohamed Nor Azhari bin Azman <mnazhari@ftv.upsi.edu.my>

Dear Editor

I m sorry for the format mistake and I have done the correction template as advised.

If there are any mistake, I willing to do the correction again.

Thank you.
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4. Revised by reviewer: 30 April 2019

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Paper ID OT18162 /Review of a paper, First Round Result/

Jestec <Jestec@taylors.edu.my>
To: "paimanupy@gmail.com" <paimanupy@gmail.com>, "paiman@upy.ac.id" <paiman@upy.ac.id>

Tue, Apr 30, 2019 at 7:22 AM

Dear Author

The **first round** of the review process has been completed.

I am glad to advise that your paper has been conditionally accepted for publication with

¨ No modification þ Minor corrections þ major modification.

Attached herewith, please find

¨ 1 ¨ 2 ¨ 3 ¨ 4 ¨ 5 þ 6 ¨ 7 ¨ 8 ¨ 9 reviewers' reports.

Please notice the following:

1- Address all the concerns/recommendations of the reviewers

2- All amendments made are to be highlighted in red color in the revised paper.

3- Send an outlining following the instructions in the attached file on how did you address each reviewers' concern/recommendations.

4- In order to complete the review process on time, we highly appreciate it if we can receive the revised paper within **three weeks** from today.

5- In case that you will need more time to complete the revision, please indicate how much time you need via an email so we can get the approval from the Editorial Board.

Please note that the final acceptance of the paper depends on the final decision of the Review Panel and after the paper successfully passed all the review rounds.

Best regards

Assoc. Prof. Dr. Abdulkareem Sh. Mahdi Al-Obaidi, CEng MIMechE

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OUTLINING HOW THE ISSUES ARE ADDRESSED

Title of paper:	Soil Solarization for Control of Weed Propagules

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2. All amendments made are to be highlighted in red color in the revised paper.

Reviewer # 1

Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☐	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
• Update the reference with symbol in yellow color	Y	Done

(Please add more rows if needed)

Reviewer # 2

Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☐	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
1. The importance of this research was stated in introduction's part. Nevertheless, there are only 3 references from 2010 onwards. Authors may add more recent references (if any).	Y	We have added 2 more references
2. The methods, results and discussion are inline. The type, brand of apparatus/tools used in each experiment should be indicated (if any). For example, the type and tools brand used for measuring light transmittance	N	

Comments	Addressed (Y/N)	Reply/Action taken
3. Section 3.2 Maximum soil temperature (Please put the reference for the discussion of last paragraph of this section) “The heat…..soil temperature”.	Y	It was right in the section 3.6. We have already inserted the reference: [5], [9].
4. Section 3.8 Weed propagules in plots (Please insert Table 7 as mentioned in the sentences of this section).	N	We have inserted the table
5. The conclusions are reflected upon the aims. However, the recommendations that might be used by others for future work should be conveyed. (if any)	Y	

(Please add more rows if needed)

Reviewer # 3				
Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☑	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
Dear Author, The paper is seen to be positively contributing for agriculture industry. The content is good but you may want to consider scientific analysis for your future work. Regards	Y	Thank you

(Please add more rows if needed)

Reviewer # 4				
Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**

Please tick	☐	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
1. The article requires English editing service for quality improvement.	Y	Done
2. Authors can add up to 5 keywords. At present, only 3 keywords were provided.	Y	Done
3. Page 3 – Materials and methods i) Rewrite paragraph 3 (second sentence) ii) Paragraph 1- The unit of thickness of PE sheets should be micrometer iii) Paragraph 5 – state the unit of light intensity (i.e: 1300 W) iv) Paragraph 4 - It might be a good idea for authors to include a schematic diagram that represents the overall experimental work. v) Paragraph 6 – the methodology section should be written in past tense	Y	We have already revised the suggested corrections
4. Table 2 – Instead of writing No. observation in the 1st, 3rd and 5th columns, maybe authors can write ‘day’.	Y	We have changed the ordinal number to Day 1, Day 2, ….
5. Page 6 – last line. The word ‘heart’ should be changed to ‘heat’.	Y	Done
6. The discussion section has lack of references to support authors’ arguments or explanation. Please add more references in each of the subsections.	Y	We have added more references [18], [19], [21]
7. Fig. 1 – spelling error of ‘Replected’	Y	Done (change in Fig. 2)
8. Page 10. Authors did not provide Table 7 even though it was mentioned in the text. Weed species names were mentioned in the last paragraph. The names should be presented in the methodology section. How did authors confirm the weed species?	Y	We missed Table 7. Now we have already attached the table. The weed species was the result of the observation. Therefore, it should not be presented in the methodology section.
9. References section – all scientific names of the weed species should be spelled in italic (check Refs 7, 14). Authors must check and follow the	Y	Done

standard format of writing the reference as mentioned in the 'Guides for authors'.

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Reviewer # 5				
Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☐	☐	☑	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
Dear Editor, Thank you for sending this manuscript for review. Authors should reduce plagiarism as per your journal policy. This paper is accepted after proper grammar, language and plagiarism check as per your journal policy. In this area in depth discussion is required to consider this paper for publication. Thanks and Regards,	Y	We have checked this paper for plagiarism and sent Turnitin result. We have also consulted this paper for appropriate grammar.

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Reviewer # 6				
Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☐	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**

The research scope is interesting and the amount of work in a methods section is impressive. However, more citations are needed to support/discuss the results in a results and discussion section. Please refer to the corrections/suggestions in the text (track changes and comments).	Y	We have added 5 citations: [5], [7], [18], [19], [21] We have already revised the suggested corrections

(Please add more rows if needed)

Reviewer # 7

Final Recommendation	**Accepted without modification**	**Accepted with minor corrections**	**Accepted with major modification**	**Rejected**
Please tick	☐	☑	☐	☐

Comments	**Addressed (Y/N)**	**Reply/Action taken**
Improve abstract. The information in the introduction is adequate. However, the authors need to improve the style of writing. The quality of the writing skills is need to be improved. It is recommended the authors consult with the native English person to improve the quality of the manuscript so that the paper is clearly readable.	Y	We have consulted this paper to native English speaker.

(Please add more rows if needed)

Gmail

Paiman UPY <paimanupy@gmail.com>

Paper ID OT18162 /Review of a paper, First Round Result/

Jestec <Jestec@taylors.edu.my>
To: Paiman UPY <paimanupy@gmail.com>

Fri, May 10, 2019 at 5:09 PM

[Quoted text hidden]

5. Submit Revision: 17 Mei 2019

Gmail — Paiman UPY <paimanupy@gmail.com>

Paper ID OT18162 /Review of a paper, First Round Result/

Paiman UPY <paimanupy@gmail.com> — Fri, May 17, 2019 at 2:09 PM
To: Jestec <Jestec@taylors.edu.my>

Dear Jestec Editorial team,

Herewith I attach the revised manuscript and the outlining reviewer comments.

Best regards

Paiman
[Quoted text hidden]

2 attachments

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Article Revision:

SOIL SOLARIZATION FOR CONTROL OF WEED PROPAGULES

PAIMAN[1]*, PRAPTO YUDONO[2], BAMBANG HENDRO SUNARMINTO[3] AND DIDIK INDRADEWA[4]

[1]Departement of Agrotechnology, Faculty of Agriculture, Universitas PGRI Yogyakarta, Jl. PGRI I Sonosewu No. 117, Bantul, Yogyakarta 55182, Indonesia
[2,3,4]Faculty of Agriculture, Universitas Gadjah Mada, Bulaksumur, Sleman, Yogyakarta 55281, Indonesia
*Corresponding Author: paiman@upy.ac.id

Abstract

One of the problems of cropland was competition with weeds. Weeds grow from the reserve of weed propagules in the soil. This research was conducted in Yogyakarta, Indonesia. The aims of the research to know the effects of soil solarization on weed propagules in the soil. The research was started with a survey to select land overgrown by homogenous of weed species. The research consisted of two factors and arranged in the randomized complete block design (RCBD), replicated three times. The difference between average of the treatment was compared using DMRT at 5% significant levels. The first factor was colored polyethylene (PE) films, which consisted of three levels: black, red and transparent. The second factor was the duration of soil solarization, which consisted of three levels: 10; 20; and 30 days. One treatment was non-solarization as control. The results of the research showed that soil solarization was able to reduce weed propagules in the soil depth. The effect of soil solarization would be more effectively reduce the greatest weed propagules up to 9-12 cm soil depth. Soil solarization for 30 days was more frequently common in days in high soil temperature. The using transparent PE films and soil solarization for 30 days are more effectively reduce 77.8% of weed propagules in 0-3 cm soil depth.

Keywords: Soil solarization, Colored PE films, Soil temperature, Soil depth, Weed propagules

1. Introduction

A single weed in one of the life cycle can produce the amount of propagule and dispersal drop to the soil around, and many of these seeds may germinate, while others remain dormant for an extended period of time. Weed seed usually infests the soil of cropland in the amount of million per acre [1]. Dormancy is an internal condition of the seed that impedes its germination under otherwise adequate hydric, thermal and gaseous conditions [2]. Some weed seeds are deeply buried in the soil, while others lie on the surface or in the litter layer just above the soil surface.

In pastures, some 64-99.6% of all weed seeds were found in the upper 4-inch layer of soil, with greater numbers in the 1 to 4-inch layer than in the surface to 1-inch layer [1]. Types of propagules were in forms of the seed, rhizome, stolon, tuber, and bulb.

Weeds seed remain viable in various periods of time, depending on species involved when buried in soil or stored in flowing fresh water. Weed seeds remain in viable but dormant condition for many years until conditions favor germination [1]. The seed or vegetative part has a period of metabolic quiescence usually termed dormancy after it is produced. During this stage, the seed or vegetative part does not resume growth, even though all environmental conditions seem to be favorable [3]. Soil tillage can cause weed propagules germination. Before germination, weed propagules would able to control with soil solarization.

Soil solarization is a hydrothermal process that utilizes the sun's energy to heat moist soil that is mulched under PE films. The basic concept of soil solarization is to use transparent plastic films to allow transmission of light energy to the soil, where it is absorbed and used to heat the soil. The transparent plastic film decreases convective heat loss so that increased soil temperature was achieved. If the temperature under the plastic film and in the soil reaches a sufficiently high temperature, weed and other plant pests are damaged or killed [4]. The transparent plastic mulch was maintained at acceptable levels of soil cover (> 80%) and hence the soil warming efficiency [5]. Soil solarization is a special mulching technique in which moist soil is covered by PE films and heated by solar radiation for several weeks [6]. The colored of PE films is an important parameter in governing the obtaining solar insolation and in reducing the return of longwave radiation. Black, opaque, or translucent plastics were not suitable for solarization, because instead of letting radiation pass through and heat the underlying soil, solar energy is absorbed and radiated back into the air with only slight warming of the surface soil. Thin, transparent plastic films appear to achieve the best results [7].

Soil solarization, a method of chemical-free pest treatment, is a practical and cost-effective way to treat organic farming soil. This method uses PE films to capture solar radiation that heats the soil [8]. Soil solarization with transparent PE films can increase soil temperature up to 52 ºC, but no mulched only 36 ºC. Soil heating was influenced by soil depth. The temperature was higher in 5 cm soil depth than 10 cm [9]. Soil solarization can increase soil temperature in 5 and 10 cm soil depth were 50.6 and 47.9 ºC than non-solarization which were 37.0 and 34.9 ºC [10]. Soil solarization can increase soil temperature of 11; 8; 7; and 5 ºC than non-solarization in 5; 10; 20; and 30 cm soil depth [11]. Soil solarization in 5 and 15 cm soil depth can produce soil temperature of 10.6 and 6.6 ºC higher than non-solarization [12].

High soil temperature can decrease the dormant period of weed propagules or induce to become secondary dormancy. A long period of solarization can eradicate weed propagules [13]. The soil temperature was higher than the optimum temperature of germination could damage the enzyme. The effect of soil temperature on weed varied depends on the duration of solarization, soil depth and weed species. Temperature above 50 ºC at 5 cm was recorded 31 (2005) and 51 (2006) days in solarization but for 7 (2005) and 18 (2006) days in non-solarization soil [14]. Soil solarization for 32 days is the best treatment and can decrease 79% of weed propagules germination than without solarization [12]. Soil solarization for 60 days can decrease 86% of *Cyperus rotundus* growth in carrot cultivation [10].

Therefore, soil solarization is the best solution for pre-emergent weed control. This experiment was conducted to choose the suitable colored PE films and the most effective duration of soil solarization for suppressing weed propagules in the soil depths.

2. Materials and Methods

2.1. Land Surveying

The research was conducted in Sleman, Yogyakarta. The research was started by surveying for selecting land overgrown by homogenous weed species. If the obtained community coefficient ≥ 75% [15], it means that both weed communities were homogenous. Thus, the research can be conducted on this land.

The materials used black and red colored PE films and transparent one which 120 cm wide and 0.03-mm thick, soil samples, cardboard dos, and weeds. The tools were tub plastic germination, knives, sprayer, digital scales, soil thermometer, and light meter type LX-101.

2.2. Experimental design

The research consisted of two factors and arranged in the randomized complete block design (RCBD) with replicated three times. The first factor was the colored PE films which consisted of three types; black; red and transparent. The second factor was the duration of soil solarization which consisted of three levels; 10; 20; and 30 days. One treatment was non-solarization as control. This research required 30 plots.

2.3. Light transmittance

The light transmittance of colored PE films was done in an unshaded place. Light transmission was measured from transmitted light was divided incoming light that multiplied by 100% and repeated 20 times in a day by the light meter.

The size of plots was made of 2 m length, 1 m width and 0.2 m high and directed horizontal from east to west and distance both plots were 0.5 m. Plots were covered with colored PE films for the duration of 30; 20; and 10 days soil solarization. Watering on both plots were to keep the soil moisture. According to Okta et al. [16], moisture content analysis was carried out by the gravimetric method.

Schematic diagram that represents the overall experimental work can be seen in Fig. 2.

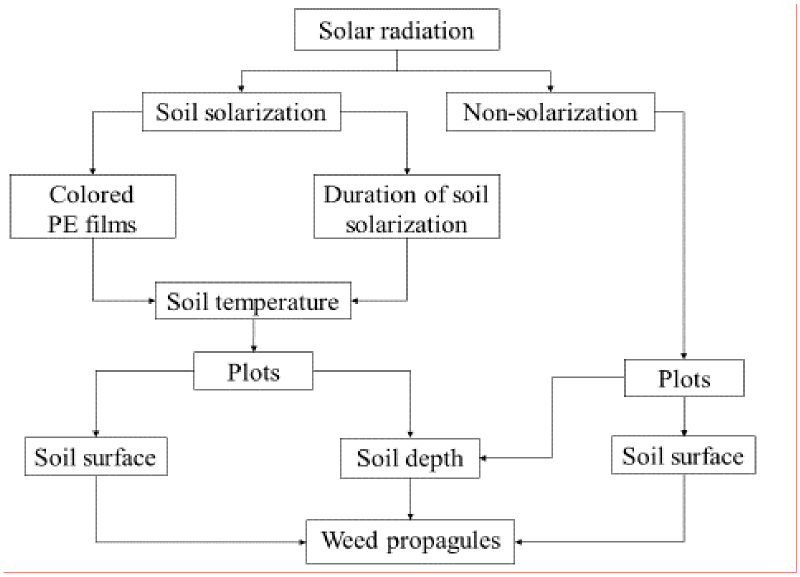

Fig. 1. Schematic diagram that represents the overall experimental work

2.4. Sunlight intensity

Light intensity was conducted in 1.5 m above of the plots and repeated three times at 13.00 PM Western Indonesia Time (WIT) within 30 days. Soil temperatures were measured at 0-3; 3-6; 6-9; and 9-12 cm soil depth at 14.00 WIT with a soil thermometer. Soil solarization treatment lasted together.

2.5. Weed propagules resistant in the soil depth

After soil solarization finished, the colored PE films were removed. Then soils sample were taken from 0.00225 m³ (25 cm x 30 cm x 3 cm) (width, length, and depth). Sample taken from soil depth 0-3; 3-6; 6-9; and 9-12 cm as much 30 plots and replicated three times, so there were 120 (4 x 30) soils sample. The drying soil samples were conducted within 4 days and each soil sample was given a label. After this, then each soil sample was placed into a tub plastics germination with a size of 25 x 30 x 5 cm (width, length and high) and took place in a greenhouse. Watering is applied in a tub plastic germination to keep the soil moisture. A few days later of weed propagules germinated. After 42 days, weed propagules grew and observable. The number of weed could be calculated.

2.6. Weed propagule resistant in plots of the soil surface

After colored PE films were removed from plots, thus weed propagules resistant would grow. And then 42 days from germinating, weeds were observed from sample in size of 50 x 50 cm (width and length) or 0.25 m². Then the number of weed could be calculated. The number of weeds grows as an illustration of weed propagules resistant.

2.7. Statistical analysis

The data of soil temperature and weed propagules were analyzed using analysis of variance (ANOVA) at the 5% significant levels [17]. The difference between the average of the treatment was compared using DMRT at 5% significant levels.

3. Results and Discussion

3.1. Light transmittance

Pre-emergent weed control can conduct with various methods. One of them is the physical method that utilizes solar energy by using PE films to allow the transmission of light energy to the soil. The colored PE films determined light transmittance. The observation showed that PE films of transparent and red were able to transmitted light, whereas black is not. It can be seen in Table 1.

Based on Table 1 can be explained that transparent PE films have a high capacity to transmit the light and followed by red PE films. Transparent and red PE films have translucent properties, showing that most of the sunlight intensity on the upper surface of the PE films were able to pass on to the bottom surface. But of the black PE films was not able to pass on the light intensity. According to Marenco and Lustosa [6], transparent PE films are recommended for soil solarization because of its high transmittance of short wave (0.3-3 μm) radiation, and its low transmittance of long wave (4-40 μm) radiation.

Table 1. The light transmitted (%) by colored PE films.

Parameter	Colored PE films		
	Red	Black	Transparent
Light transmitted (%)	67.4	0	93.5

3.2. Sunlight intensity

The sunlight intensity was measured by a light meter at foot-candle (FC) in 1.5 m soil above. The sunlight intensity can be seen in Table 2. The average of sunlight intensity at the observation number of 1 to 10 were recorded lower (4,848 FC) than at the observation number of 11 to 20 (7,680.3 FC) and 21 to 30 (8,087.3 FC). The high of sunlight intensity only occurred a few days from the observation because of the time of the research coincided with the rainy season. Especially, at the observation number of 1 to 10, the sunlight intensity in the atmosphere disturbed by clouds, so incoming light to earth was low.

The success of soil solarization depends on the sunlight intensity to the earth, because it is correlated with the soil temperature. According to Onwuka and Mang [18], soil temperature varies seasonally and daily which may result from changes in radiant energy and energy changes taking place through the soil surface.

Table 2. The sunlight intensity in 1.5 m soil above of the plots

Observa-Tion	Light intensity (FC)	Observa-tion	Light intensity (FC)	Observa-tion	Light intensity (FC)
Day 1	3,333.3	Day 11	6,033.3	Day 21	9,853.3
Day 2	3,673.3	Day 12	6,996.7	Day 22	10,830.0
Day 3	8,023.3	Day 13	7,336.7	Day 23	9,646.7
Day 4	4,740.0	Day 14	11,483.3	Day 23	8,863.3
Day 5	5,473.3	Day 15	2,880.0	Day 25	7,820.0
Day 6	4,316.7	Day 16	10,320.0	Day 26	1,883.3
Day 7	7,813.3	Day 17	9,913.3	Day 27	9,886.7
Day 8	2,356.7	Day 18	10,880.0	Day 28	9,710.0
Day 9	6,263.3	Day 19	1,703.3	Day 29	8,850.0
Day 10	2,496.7	Day 20	11,056.7	Day 30	3,530.0
Average	4,848.9		7,860.3		8,087.3

Remarks: The observations were conducted within 30 days

3.3. Soil physical properties

The soil type for the experiment was Inceptisol. The analysis of soil physical properties can be seen in Table 3. Based on Table 3 showed that the soil type for experiment including in soil texture of sandy loam (73% sand, 5,97 clay, and 21% silt). The soil was dominated by 73% sand. Soil porosity including the moderate (31.6%). According to Harahap [19], the texture of the inceptisol consisted of 72% sand, 11% clay, and 17% silt. Inceptisol has texture of sandy loam. The Soil that higher sands content will be easily to water penetration and low water ability than the soil has higher clay.

Table 3. The analysis of soil physical properties

Soil variable	Unit	Value	Soil character
Texture			
• **Sand**	%	73.0	Sandy loam
• **Silt**	%	21.0	
• **Clay**	%	5.97	
Bulk Density	g/cm^3	1.45	
Particle density	g/cm^3	2.14	
Porosity	%	31.6	

3.4. Soil temperature

The analysis of variance on soil temperature showed that there were significant between soil solarization and non-solarization in 0-3; 3-6; 6-9; and 9-12 cm soil depth. There was no significant interaction between colored PE films and duration of soil solarization on soil temperature in the soil depth. The Average of soil temperature on soil depths can be seen in Table 4.

Based on Table 4 showed that soil solarization treatment caused higher soil temperature compared to non-solarization in various soil depths. Soil solarization with using the red and transparent PE films was able to make higher soil temperature and significantly different from the black in all of the soil depth. In the soil depth, the effect of colored PE films trends decline. According to Sahile et al. [20], reported that transparent PE films were found slightly more effective than a black one in transferring solar radiation to the soil.

Soil solarization for 30 days was given the average of soil temperature lower than at 20 and 10 days soil solarization because at the early observation of the light intensity was very low at the day's observation of 1 to 10 (Table 2). Soil temperature was affected by the light intensity in the atmosphere. If light intensity in the atmosphere was low, so the effect on soil temperature low too. The effect of duration of soil solarization trends declines in soil deeply. According to Nwankwo and Ogagarue [21], temperature functions are greatest at the surface than at the deeper subsoil.

Table 4. The average of soil temperature (^{0}C) in the soil depths (cm)

Treatment	Soil depths (cm)			
	0-3	**3-6**	**6-9**	**9-12**
Orthogonal contras				
Treatment	47.0 x	45.0 x	42.6 x	40.5 x
Non-solarization	35.9 y	34.8 y	33.7 y	32.4 y
Colored PE films				
Black	43.8 b	42.3 b	40.6 b	38.6 b
Red	48.5 a	46.3 a	43.6 a	41.3 a
Transparent	48.7 a	46.4 a	43.8 a	41.7 a
Duration of soil solarization (days)				
10	47.8 p	45.7 p	43.2 p	41.2 p
20	47.7 p	45.7 p	43.0 p	40.8 p
30	45.6 q	43.7 q	41.5 q	39.5 q
Interaction	(-)	(-)	(-)	(-)

Remarks: Number in the same column followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

3.5. Mechanism of soil solarization

Soil temperature was resulted from all combination magnitude radiation and heat flow in soil. The red, black and transparent PE films were able to make higher soil temperature than non-solarization in the soil depth. The PE films decrease convective heat loss so that increased soil temperature was achieved, so heat energy balance can depend on the soil surface. Soil temperature could reach a maximum in plots covered with PE films. Incoming solar radiation to penetrate the PE films are forwarded to the soil surface, then radiation energy is converted into heat energy. Heat energy through the soil surface conducted to the soil depth more deeply. According to Nwankwo and Ogagarue [21], heat loss near the soil surface than the deeper subsoil. Also, some of the heat energy received from the sun is radiated back at the near surface because of the light colored nature of the formation. The inner layers, therefore, retain more heat than the outer layer. Mechanism of soil solarization in the soil depth can be seen in Fig. 2.

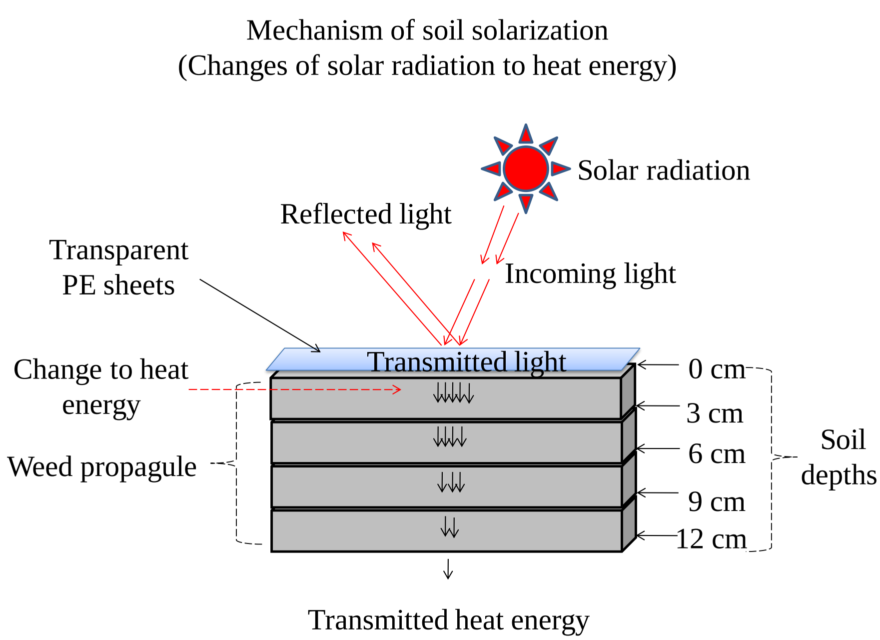

Fig. 2. Mechanism of soil solarization in the soil depths

Fig. 2 can be explained that solar radiation is emitted to the earth in form of short wave energy and passes transparent PE films in the soil surface, thus until soil surface was changed to heat energy and absorbed by soil that causes to increase the soil temperature. The process of heat displacement in the soil is conduction. The heat displacement in the soil has occurred from layers to layers in the soil depth. Heat received in the soil surface transferred to the soil more deeper. Heat transferred take some time. Fluctuations of temperature the soil depth will high on the soil surface and getting smaller with increasing the soil depth. The maximum temperature on the soil surface will be achieved at the time of intensity of solar radiation reaching a maximum. But in the soil more deeper, then the maximum temperature is achievable in some time later. Heat is transferred from the soil surface into soil depth will have an effect on weed propagules.

3.6. Maximum soil temperature

Based on the daily measurement of soil temperature could make the interval of soil temperature. Table 5 showed that in non-solarized plots never occurs the soil temperature above 50 ºC during observation. Soil temperature above 50 ºC recorded more frequently occurred using transparent and red PE films. Whereas, it rarely occurred where using black PE films. According to Subrahmaniyan et al. [5], the transparent plastic mulch was maintained at acceptable levels of soil cover (> 80%) and hence the soil warming efficiency.

In 0-3 cm soil depth, the soil temperature above 50 ºC more frequently occurred than in 3-6 cm soil depth. The days that soil temperature above 50 ºC on plots depends on colored PE films and acceptance of the amount of heat that can be forwarded. Transparent and red PE films are causing soil temperature of 50 ºC above were occur more frequently during the experiment than in black. Soil temperature above 50 ºC only occur in 0-3 and 3-6 cm soil depth, whereas in the soil more deeply does not occur. According to Yaqub and Shahzad [9], the soil heating by PE mulching was also affected by the soil depth. The higher soil temperatures were recorded at the 5 cm depth as compared to 10 cm depth. However, at both 5 and 10 cm depths, PE mulching produced significantly higher soil temperatures than non-mulched soils at the same depth.

Higher soil temperature would inhibit germination of weed seeds, as it would effect enzymatic action. The amylase enzyme would optimally work at normal temperature and its activity would decrease with the deviation from normal temperature. The activity of amylase enzyme would be disrupted in breaking down starch into sugar when in high soil temperature. According to Dahlquist et al. [22], reported that temperature of 50 ºC above was lethal for weed of all species. Soil temperature provided effects on weed propagules germination. Weed propagules required special temperature for their germination in optimum temperature. The optimum temperature of the seed enzyme varied depending on the individual type of weed propagules. The higher soil temperature causes the greater enzyme activity within weed seeds.

Table 5. The number of days based on the interval of soil temperature

Colored PE films	Duration of soil solarization (days)	Interval of soil temperature (ºC)				
		< 36	36-40	41-45	46-50	>50 *)
		Soil depth of 0-3 cm				
Non-solarization	30	12.4	14.7	2.7	0.0	0.0
Black	10	0.0	2.0	4.0	4.0	0.0
	20	0.0	4.0	6.7	8.3	1.0
	30	2.0	7.0	13.3	6.0	1.7
Red	10	0.0	1.0	0.3	5.0	3.7
	20	0.0	1.3	2.3	7.7	8.7
	30	1.0	4.3	4.7	10.0	10.0
Transparent	10	0.0	0.0	0.7	4.3	5.0
	20	0.0	0.7	3.0	7.0	9.3
	30	1.0	3.7	6.0	9.0	10.3

			Soil depth of 3-6 cm			
No solarization	30	18.0	11.0	1.0	0.0	0.0
Black	10	0.0	2.4	6.3	1.3	0.0
	20	0.0	3.7	12.6	3.7	0.0
	30	3.3	8.0	13.3	4.7	0.7
Red	10	0.0	0.6	1.7	6.0	1.7
	20	0.0	2.4	3.3	12.0	2.3
	30	2.0	3.7	8.6	12.7	3.0
Transparent	10	0.0	0.0	2.4	6.3	1.3
	20	0.0	1.3	6.0	8.7	4.0
	30	2.3	4.7	7.7	11.3	4.0

Remarks: *) Soil temperature of 50 ºC and above occurs only in 0-3 and 3-6 cm soil depth

3.7. Weed propagules in the soil depth

The analysis of variance on the number of weed propagules resistant in the soil depth after soil solarization showed that there was a significant difference between soil solarization and non-solarization. No significant different interaction between the colored PE films, and duration of soil solarization on the number of weed propagules resistant in the soil depth. The number of weed propagules resistant in of soil depth after soil solarization can be seen in Table 6.

Table 6 showed that soil solarization can suppress weed propagules in various soil depth. By reducing the light transmittance, the colored mulches were able to resistant the growth of weeds despite their heavy infestation, while the clear mulch had weaker suppression of weed [23]. The types of weed propagules were observed in forms of the seed, rhizome, stolen, and tuber. The use of transparent PE films can suppress weed propagules more high than red and black in 0-3 cm soil depth (74.4; 67.9; and 50.1%, respectively). In 3-6 and 6-9 cm soil depth, transparent PE films can reduce weed propagules than black and not significant with red PE films.

Soil solarization for 30 days in 0-3 cm soil depth caused the weed propagules lower resistance than 10 and 20 days of solarization (24.4; 36.2; and 48.7%, respectively). Some weed propagules died in 0-3 and 3-6 cm soil depth, except four weed propagules species namely *Cleome viscosa* (L.), *Ludwigia peruviana* (L.) H.Hara, *Phyllanthus urinaria* (L.), and *Physalis angulata* (L.). According to Asharafi et al. [14], soil solarization with clear PE films killed about 95% of buried viable seed, and induced secondary dormancy in the remaining 5%. In the soil deeply, indicated that the effect of colored PE films and duration of soil solarization decreases. Soil temperature in 0-3 and 3-6 cm soil depth effectively suppress the weed propagules.

Table 6. Weed propagules resistant (%) in the soil depth with a plot in size of 25 x 30 x 3 cm

Treatment	**Soil depths (cm)**			
	0-3	**3-6**	**6-9**	**9-12**
Orthogonal contras				
Treatment	37.0 y	64.7 y	79.1 y	86.2 y
Non-solarization	100.0 x	100.0 x	100.0 x	100.0 x
Colored PE films				
Black	49.9 a	78.9 a	84.4 a	92.4 a
Red	32.1 b	64.5 ab	80.7 ab	87.5 a
Transparent	25.6 b	54.7 b	72.4 b	78.5 b
Duration of soil solarization (days)				
10	48.7 p	78.8 p	91.5 p	92.8 p
20	36.2 q	64.0 q	78.2 q	83.8 q
30	24.4 r	55.4 q	67.7 q	76.7 q
Interaction	(-)	(-)	(-)	(-)

Remarks: Number in the same column followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

3.8. Weed propagules resistant in plots

The analysis of variance on weed propagules resistant in plots showed that there was a significant difference between soil solarization and non-solarization. No significant different interaction between the colored PE films and duration of soil solarization on weed propagules resistant in the plots. Weed propagules grow in plots can be seen in Table 7.

Based on Table 7 can be explained that soil solarization is able to reduce weed propagules. Transparent PE films could highly reduce weed propagules and significantly different from black and red PE films. Soil solarization using transparent PE films more effectively reduce weed propagules in plots. Soil solarization for 30 days can reduce the highest weed propagules and significantly different from 20 and 10 days of solarization.

Weed species resistant in all of the plots were covered with transparent PE sheets: *Cleome viscosa* (L.), *Cyperus rotundus* (L.), *Alternanthera philoxeroides* (L.) D.C, and *Cynodon dactylon* (L.) Pers. Using of transparent PE films and soil solarization for 30 days can reduce 77.8% of weed propagules and 22.2% still resistant (Table 7). According to Marenco and Lustosa [6] reported that solarization reduced weed biomass and density in about 50% of weed species.

Table 7. Percentage of weed propagules resistant (%) in size of 50 x 50 cm square plots

Colored PE films	Duration of soil solarization (days)			Average
	10	20	30	
Black	75.2	62.3	51.9	63.1 a
Red	52.9	35.7	26.8	38.5 b
Transparent	45.0	31.6	22.2	33.1 c
Average	57.7 p	43.2 q	33.8 r	(-)
Treatment				44.9 y
Non-solarization				100.0 x

Remarks: Number in the same column followed by the same characters are not significantly different based on DMRT at 5% significant levels. (-) = no significant interaction.

4. Conclusions

The research of soil solarization was able to reduce weed propagules in the soil depth. Some concluding observation from this research is given below.

- The effect of soil solarization would be more effectively reduce the greatest weed propagules up to 9-12 cm soil depth.
- Soil solarization for 30 days was more frequently identified the greater number of days that high soil temperature.
- The using transparent PE films and soil solarization for 30 days are more effectively reduce 77.8% of the weed propagules in 0-3 cm soil depth.

Abbreviations

ANOVA	Analysis of Variance
DMRT	Duncan's New Multiple Range Test
PE	Polyethylene
FC	Foot Candle

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