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SOIL SOLARISATION FOR CONTROL OF WEED PROPAGULES

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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 solarisation 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 the average of the treatment was compared using DMRT at 5% significant levels. The first factor was coloured polyethylene (PE) films, which consisted of three levels: black, red and transparent. The second factor was the duration of soil solarisation, which consisted of three levels: 10; 20; and 30 days. One treatment was non-solarisation as control. The results of the research showed that soil solarisation was able to reduce weed propagules in the soil depth. The effect of soil solarisation would be more effectively reduce the greatest weed propagules up to 9-12 cm soil depth. Soil solarisation for 30 days was more frequently common in days in high soil temperature. The using transparent PE films and soil solarisation for 30 days are more effectively reduce 77.8% of weed propagules in 0-3 cm soil depth.

Keywords: Soil solarisation, Coloured 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. Weed seed usually infests the soil for cropland 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, depending on species involved when buried in soil or stored inflowing freshwater. Weed seeds remain in viable but dormant condition for many years until conditions favour 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 favourable [3]. Soil tillage can cause weed propagules germination. Before germination, weed propagules would able to control with soil solarisation.

Soil solarisation 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 solarisation 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 solarisation is a special mulching technique in which, moist soil is covered by PE films and heated by solar radiation for several weeks [6]. The coloured 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 polarization, because instead of letting radiation pass through and heat the underlying soil, solar energy is absorbed and radiated back into the air with an only slight warming of the surface soil. Thin, transparent plastic films appear to achieve the best results [7].

Soil solarisation, 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 solarisation with transparent PE films can increase soil temperature up to 52-degree celcius (°C), but no mulched only 36 °C. Soil heating was influenced by soil depth. The temperature was higher in 5 cm soil depth than 10 cm [9]. Soil solarisation can increase soil temperature in 5 and 10 cm soil depth were 50.6 and 47.9 °C than non-solarisation, which, were 37.0 and 34. °C [10]. Soil solarisation can increase soil temperature of 11; 8; 7; and 5 °C than non-solarisation in 5; 10; 20; and 30 cm soil depth [11]. Soil solarisation in 5 and 15 cm soil depth can produce soil temperature of 10.6 and 6.6 °C higher than non-solarisation [12].

High soil temperature can decrease the dormant period of weed propagules or induce to become secondary dormancy. A long period of solarisation 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 solarisation, soil depth and weed species. Temperature above 50 °C at 5 cm was recorded 31 (2005) and 51 (2006) days in solarisation but for 7 (2005) and 18 (2006) days in non-solarisation soil [14]. Soil solarisation for 32 days is the best treatment and can decrease 79% of weed propagules germination than without solarisation [12]. Soil solarisation for 60 days can decrease 86% of *Cyperus rotundus* growth in carrot cultivation [10].

Therefore, soil solarisation is the best solution for pre-emergent weed control. This experiment was conducted to choose the suitable coloured PE films and the most effective duration of soil solarisation 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 coefficient of community ≥ 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 coloured 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 coloured PE films, which consisted of three types: black; red and transparent. The second factor was the duration of soil solarisation, 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 coloured 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 coloured PE films for the duration of 30; 20; and 10 days soil solarisation. Watering on both plots were to keep the soil moisture. According to Bani 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. 1.

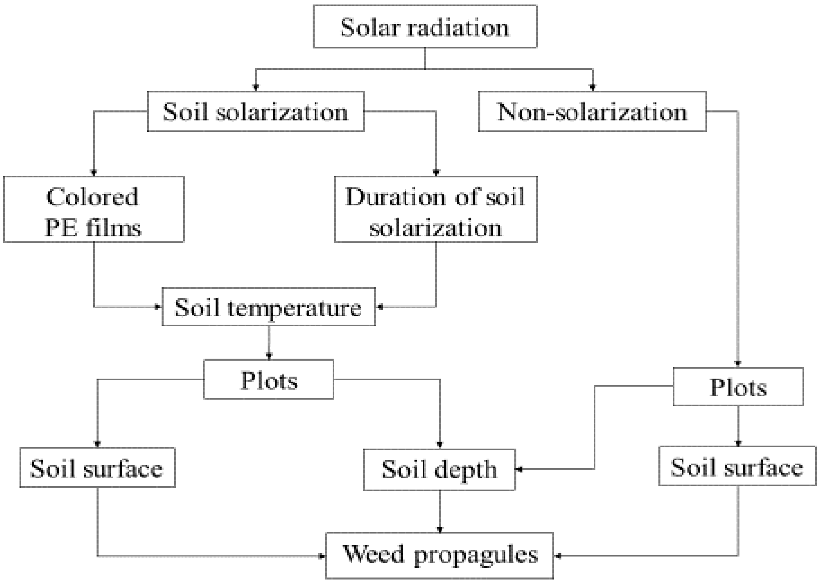

Fig. 1. Schematic diagram that represents the overall experimental work.

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 solarisation treatment lasted together.

2.5. Weed propagules resistant in the soil depth

After soil solarisation finished, the coloured PE films were removed. Then soil samples were taken from 0.00225 m^3 (25 cm × 30 cm × 3 cm) (width, length, and depth). Sample was 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 × 30) soil samples.

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 cm × 30 cm × 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 coloured PE films were removed from plots, thus, weed propagules resistant would grow. And then 42 days from germinating, weeds were observed from the sample in size of 50 cm × 50 cm (width and length) or 0.25 m^2.

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 analysed 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 coloured 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. However, the black PE films were not able to pass on the light intensity.

According to Marenco and Lustosa [6], transparent PE films are recommended for soil solarisation 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. Light transmitted (%) by coloured PE films.

Parameter	Coloured 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 solarisation 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. Sunlight intensity in 1.5 m soil above of the plots.

Observation	Light intensity (FC)	Observation	Light intensity (FC)	Observation	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: 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 et al. [19], the texture of the inceptisol consisted of 72% sand, 11% clay, and 17% silt. Inceptisol has a texture of sandy loam. The soil that higher sands content will be easy to water penetration and low water ability than the soil has higher clay.

Table 3. 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 (BD)	g/cm³	1.45	
Particle density (PD)	g/cm³	2.14	
Soil porosity	%	31.6	

3.4. Soil temperature

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

Based on Table 4 showed that soil solarisation treatment caused higher soil temperature compared to non-solarisation in various soil depths. Soil solarisation 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 coloured 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 solarisation for 30 days was given the average of soil temperature lower than at 20 and 10 days soil solarisation 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 solarisation 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. Average of soil temperature (^{O}C) in the soil depths (cm).

Treatment	Soil depths (cm)			
	0-3	**3-6**	**6-9**	**9-12**
Orthogonal contrast				
Treatment	47.0 x	45.0 x	42.6 x	40.5 x
Non-solarisation	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 solarisation (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 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-solarisation 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. In addition, some of the heat energy received from the sun is radiated back at the near-surface because of the light coloured nature of the formation. The inner layers, therefore, retain more heat than the outer layer. Mechanism of soil solarisation in the soil depth can be seen in Fig. 2.

Figure 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 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. However, in the soil 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.

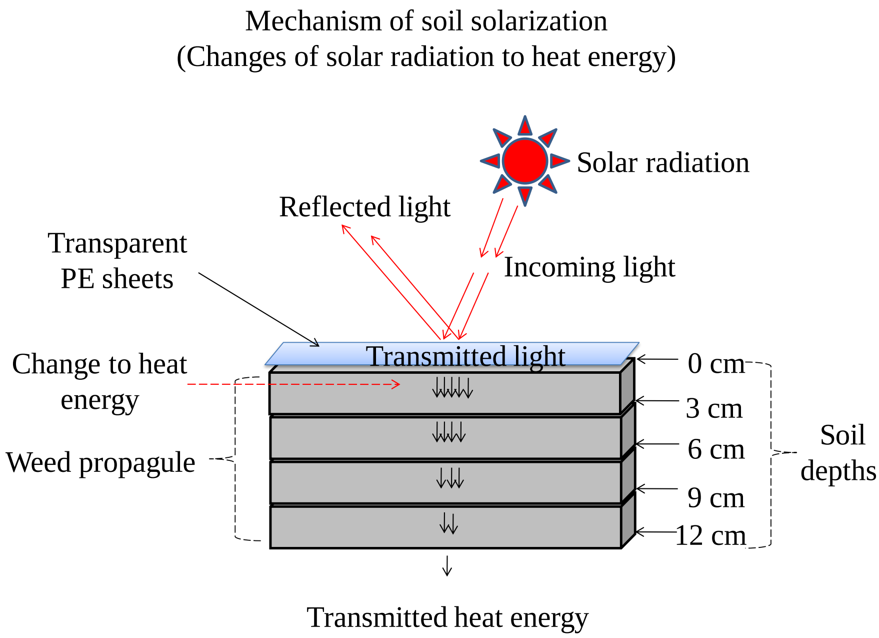

Fig. 2. Mechanism of soil solarisation in the soil depths.

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 °C during observation. Soil temperature above 50 °C recorded more frequently occurred using transparent and red PE films. Whereas, it rarely occurred was 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 °C more frequently occurred than in 3-6 cm soil depth. The days that soil temperature above 50 °C on plots depends on coloured PE films and acceptance of the amount of heat that can be forwarded. Transparent and red PE films are causing soil temperature of 50 °C above were occur more frequently during the experiment than in black. Soil temperature above 50 °C only occurs 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 affect 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 the temperature of 50 °C 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. Number of days based on the interval of soil temperature.

Coloured PE films	Duration of soil solarisation (days)	Interval of soil temperature (°C)				
		< 36	36-40	41-45	46-50	>50*)
		Soil depth of 0-3 cm				
Non-solarisation	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 solarisation	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 °C 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 solarisation showed that there was a significant difference between soil solarisation and non-solarisation. No significant different interaction between the coloured PE films, and duration of soil solarisation on the number of weed propagules resistant in the soil depth. The number of weed propagules resistant in of soil depth after soil solarisation can be seen in Table 6.

Table 6 showed that soil solarisation could suppress weed propagules in various soil depth. By reducing the light transmittance, the coloured 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 solarisation for 30 days in 0-3 cm soil depth caused the weed propagules lower resistance than 10 and 20 days of solarisation (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 solarisation 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 coloured PE films and duration of soil solarisation decreases. Soil temperature in 0-3 and 3-6 cm soil depth effectively suppress the weed propagules.

Table 6. Weed propagules resistant (percentage) in the soil depth with a plot in size of 25 cm × 30 cm × 3 cm (width, length, and depth).

Treatment	Soil depths (cm)			
	0-3	**3-6**	**6-9**	**9-12**
Orthogonal contrast				
Treatment	37.0 y	64.7 y	79.1 y	86.2 y
Non-solarisation	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 solarisation (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 solarisation and non-solarisation. No significant different interaction between the coloured PE films and duration of soil solarisation 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 solarisation is able to reduce weed propagules. Transparent PE films could highly reduce weed propagules and significantly different from black and red PE films. Soil solarisation using transparent PE films more effectively reduce weed propagules in plots. Soil solarisation for 30 days can reduce the highest weed propagules and significantly different from 20 and 10 days of solarisation.

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 transparent PE films and soil solarisation 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 solarisation reduced weed biomass and density in about 50% of weed species.

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

Colored PE films	Duration of soil solarisation (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-solarisation				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 solarisation was able to reduce weed propagules in the soil depth. Some concluding observation from this research is given below:

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

Nomenclature

BD	Bulk Density, g/cm³
PD	Particle Density, g/cm³

Abbreviations

ANOVA	Analysis of Variance
DMRT	Duncan’s New Multiple Range Test
PC	Foot Candle
PE	Polyethylene
PM	Post Meridiem
RCBD	Randominized Complete Block Design
WIT	Western Indonesia Time

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