Weed population and biomass as influenced by polyethylene film colour and soil solarization duration in maize (*Zea mays* L.) field

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Abstract
Field experiments were conducted at the University of Calabar Teaching and Research Farm, Calabar, Nigeria, to assess the impacts of polyethylene film colour and soil solarization duration on weed control in maize (Zea mays L.) field. Factorial combinations of three colors of polyethylene film (white, green, and black) and four pre-plant soil solarization durations (0, 2, 4 and 6 week- periods) were laid out in a Randomized Complete Block Design (RCBD) with three replications. Data collected on weed density, weed morphological group populations, weed dry matter and one-thousand grain weight of maize were analyzed and significant means separated using Fisher's Least Significant Difference (FLSD) at 5 % probability level. White polyethylene was more effective in weed suppression and resulted in heavier 1000-grain weight of maize compared with the green and black. On the two-year average, soil solarization for 6, 4, and 2 weeks before planting reduced weed density by 81.03, 59.26 and 30.47 %, and weed dry matter by 76.61, 66.21 and 29.97 % respectively, compared with no solarization (control). Polyethylene film colour and solarization duration effects on weed morphological group populations followed similar patterns as weed density. Interactively, the control plots produced the highest combined mean weed density, highest mean weed dry matter, and lightest mean 1000-grain weight (137.81–143.85 g). The 6-week solarization with white polyethylene which produced the least weed density, least weed dry matter, and heaviest mean 1000-grain weight (195.81 g), is recommended for maize growers in the study area as the most effective treatment combination.

Keywords: Polyethylene film colour; soil solarization duration, weed density, weed dry matter, maize

Introduction
Soil solarization is a non-chemical and environmentally friendly weed management practice which involves the use of polyethylene films or plastic sheets to minimizes weed emergence by causing thermal death to weed seeds and seedlings (Pathel *et al.*, 2005). Solarization has been successfully deployed as a crop protection technique for decades (Marenco and Lustosa, 2000), especially in advanced agriculture, and can be successfully applied in maize production (Ahmad *et al.*, 1996). Currently, there is increasing interest in the use of polyethylene film mulches as an alternative weed management method that can effectively

minimize the need for herbicide use and reduce reliance on expensive manual labour (Rayns *et al*., 2021)

Previous research findings indicate that, polyethylene film colour and the duration of soil solarization are important factors that affect the density, dry matter and composition of weeds in croplands, but to varying degrees in efficacy, depending on climate and crop selection, among other factors (Stapleton, 1991). For instance, while it was earlier demonstrated in Japan that, black polyethylene mulch reduced weeds more effectively than green polyethylene (Inada, 1973), subsequent findings in southeastern Mexico showed similarity in the performance of black polyethylene and transparent film mulches (Stapleton *et al*., 1989), while other more recent findings suggested that, transparent polyethylene sheets were more efficient in weed suppression than the black (Sahile *et al*., 2005). Recommendations of polyethylene for solarization have therefore varied from black (Abu-Irmaileh, 1991) to transparent (Kipkorir, 2016) types.

Similarly, it was reported that soil solarization for 2-6 weeks resulted in significant reductions in coverage, density and biomass of weeds compared to non-solarized treatments (Seaman-Varner and McSorley, 2012), whereas Marenco and Lustosa (2000) concluded that, soil solarization for nine weeks increased carrot yield and reduced more than 50 % of the populations of the weed species recorded in the carrot field. Although there seems to be insufficient information on the effect of integration of polyethylene colour and duration of soil solarization on weed control and crop performance, Singh (2006) reported effective weed suppression with pre-plant soil solarization using either black or transparent polyethylene for 15 to 30 days, but the transparent films for 30 days gave best weed control and 90 % increase in soybean yield in India.

There is paucity of information on the use of soil solarization for weed control in maize farms in Nigeria, where the crop is grown and consumed from the southern rainforest to the northern Sahel savanna. This research was therefore conducted to determine the impacts of different polyethylene film colours and pre-plant soil solarization duration on weed growth in a Nigerian rain forest maize field.

Materials and Methods

Field experiments were conducted in the 2016 and 2017 early (March - June) cropping seasons at the University of Calabar Teaching and Research Farm, Calabar, to determine the weed suppressive effects of different polyethylene film colours and duration of pre-plant soil solarization in a maize field. The farm is located within the University of Calabar, bound to the east by the Great Qua River, on latitudes 04^0 56'

– 04^0 57'N and longitudes 8^0 20' - 8^0 21'E, (Antigha *et al*., 2015). Calabar has a ten- month rainy season and only two-month dry season (Wikipedia, 2018). The rainfall is bimodal, separated by a short dry spell usually in August, thereby giving rise to two distinct cropping seasons – the early- (March – July) and late- (August – December) seasons (Nwagwu *et al*., 2020). A 19-year average weather data indicates that Calabar had a total annual rainfall of 4, 528 mm per annum and monthly total annual rainfall of about 2,859.84 mm (being the highest in the country), average minimum and maximum temperatures of 22.6 ^{0}C and 30.8 ^{0}C**,** and relative humidity of 77 – 91 % (Ewona and Udo, 2010).

Seedbeds measuring 2.9 m x 1.2 m were manually raised and levelled with spade. Factorial combinations of three colors of polyethylene film (black, green and white) and four pre-plant soil solarization durations (0, 2, 4 and 6 week-periods) were laid out in Randomized Complete Block Design (RCBD) with three replications. The polyethylene films with equal thickness of 100 µm were laid uniformly and anchored around the treated beds by tucking into a narrow trench and covering with soil, beginning in March each year. The 6-week solarization treatments were installed first, followed two and four weeks later by the 4- and 2- week solarization periods, respectively. At the end of the sixth week, the polyethylene films were removed with the no-solarization plots as control, before planting of maize. Maize seeds were sown at 75 cm × 25 cm spacing, two per hole, and later thinned to one, giving a population of 53,333 plants per hectare. Weed assessment was done at 3, 6 and 9 weeks after sowing (WAS). Weed density was determined by placing a 1 m x 1 m quadrat randomly on each treatment plot and the total number of weeds enclosed within the quadrat harvested, counted and recorded. The harvested weeds were then separated into morphological groups - broad leaves, grasses and sedges, and the total number in each group was pooled over the sampling periods and recorded (Nwagwu *et al*., 2020).

For weed dry matter, the harvested weeds were bulked on treatment basis and oven dried at 70 ^{0}C to a constant weight, expressed in kilogrammes per hectare. One thousand maize grains were counted from the bulked harvest from six middle plants per plot at 80 days after sowing (DAS), air-dried for seven days in an enclosure and the weight determined using a sensitive electronic balance, and expressed in grammes.

Data collected were subjected to analysis of variance (ANOVA) using the GenStat Package Version 8.1and means compared using Fisher's Least Significant Difference (FLSD) method at 5% level of probability.

Results and discussion

Weed density (no m^{-2})

The effect of polyethylene film colour was significant ($P < 0.05$) on total weed density in both years and at 3 and 6 WAS in 2017; plots with white polyethylene film had the lowest weed density, while the black had the highest values, though with statistical similarity at most sampling periods in 2016 (Table 1). The tendency of white polyethylene to control weeds better than the green and black is in agreement with the findings of Sahile *et al*. (2005) who reported that, clear polyethylene controlled weeds (*Orobanche* spp) slightly better than the black in tomato field. Possibly, the white polyethylene trapped and/or transmitted more solar heat into the soil, leading to the likely desiccation of more weed seeds and/or propagules than the green and black. On the other hand, the similarity in weed density among the green, black and white polyethylene films at some sampling periods suggests that the polyethylene mulch was effective in weed control irrespective of the film colour. This finding is in agreement with Stapleton (1991) who observed that, mulching moist soil with black polyethylene film produced similar effect in disease and weed control compared to transparent films. However, our observation differs from that of Ngouajio and Ernest (2004), who reported that white mulches had higher weed density compared to black and other coloured polyethylene mulches.

Pre-panting soil solarization significantly influenced weed density in both years. Weed density progressively declined as solarization duration increased from 0 - 6 weeks. This could be as a result of greater duration of heat trapping and subsequent killing of more weed propagules over time in the solarized plots. This finding is consistent with Marenco and Lustosa (2000), who reported progressive decline in weed populations with increasing solarization durations. It has been noted that, the longer the solarization duration, the more the soil is heated, resulting in deeper weed control and increased opportunity of biocontrol mechanism to work (Kipkorir, 2016). However, solarization for 2 weeks resulted to similar weed density as the non- solarized control at all sampling periods in the first year, probably due to short duration and shallower depth of soil heating in the 2- week solarization duration.

Although solarization for 4- and 6- week durations were consistently effective in weed density reduction, the 6-week duration gave the best control. This finding agrees with those of Chauhan *et al.* (1988), Abu-Irmaileh, (1991), Elmore *et al*. (1997), and Chase *et al.* (1998), all of whom reported that, solarization up to 6 weeks effectively reduced weed infestations in crop fields. Interactively in this study, pre-plant soil solarization for 6 weeks with white polyethylene resulted in the least weed density, indicating superiority.

Weed morphological groups (broadleaves, grasses, and sedges populations (no m^{-2})

Polyethylene film colour and pre-plant soil solarization duration significantly ($P < 0.05$) affected the populations of broad leaves, grasses, and sedges each year (Table 2). On the two year average, plots with white polyethylene film produced the lowest populations of broad leaves, grasses and sedges; plots with black polyethylene film produced the highest population of broad leaves and grasses, whereas green polyethylene film plots produced the highest number of sedges. This finding indicates that white polyethylene film was the most effective in smothering weeds across the three morphological groups studied, and hence, can be applied where either broadleaves, grasses or sedges predominate, or where they occur in mixtures, for efficient weed control. This is in agreement with Horowitz *et al.* (1983) who reported that, solarization with clear polyethylene produced effective control of annual weeds.

Every 2- week increase in solarization duration resulted to a significant decrease in weed populations across the morphological groups in both years. Thus, the reductions in weed density due to solarization as earlier observed, cut across the various weed morphological groups, thereby making soil solarization with polyethylene a viable tool for broad-spectrum weed management. It is pertinent to note that sedges, particularly *Cyperus* spp., which are noxious weeds and visually observed to be the most predominant sedges in the experimental plots, were significantly controlled by the 4- and 6- week solarization periods. This finding agrees with the report of Seman-Varner and McSorley (2012) that, soil solarization for 4 and 6 weeks reduced the population of the sedge *Cyperus rotundu*s. Also, Johnson *et al*. (2007) reported that, solarization was an important tool to manage nutsedge, which is often hard to control with regular mulches as it propagates mainly by rhizomes. Interactively, pre-plant soil solarization with white polyethylene for 6 weeks resulted in the least number of sedge weeds in both years, suggesting superiority, while the highest values were obtained from the control.

Weed dry matter (g m^{-2})

Polyethylene film colour affected weed dry matter at 6 and 9 WAS in 2017 and the total weed dry matter each year (Table 3). The yearly total and pooled mean weed dry matter were least with white polyethylene and highest with the black. Combined, the mean showed that, solarization for 2, 4, and 6 weeks before planting reduced weed dry matter by 17.86, 58.67 and 69.64 % compared with the control.

These findings are similar to those of Haidar and Sidahmed (2000), and Farid *et al*. (2014) who reported reductions in weed biomass with increasing soil solarization durations. In the same vein, Sahile *et al.* (2005) reported a 97 % reduction of weed biomass in tomato field with soil solarization for 6 weeks as compared to the weedy check.

The interaction showed that, in 2016, all the control and 2- week solarized plots produced similar weed dry matter across polyethylene colours, which were significantly ($p < 0.05$) higher than the 4- and 6- week solarized treatments. This partial ineffectiveness of the 2- week solarization could be attributed to the shortness of time these plots were solar-heated with the polyethylene films, which was probably insufficient to kill most of the weed propagules in the soil to greater depth. Subsequent hoe weeding of these plots may have therefore triggered more weed seed germination, leading to weed populations similar to those in the control. Cultivation after solarization could bring untreated soil and weed seed to the surface (Elmore, 1991), thereby leading to increased weed density through germination of the seeds.

One thousand seed weight (g)

The thousand grain weight is an important yield determining parameter that contributes to final yield of maize, and is affected by different weed management methods (Ali *et al.*, 2011). Table 4 indicates that plots with white polyethylene film produced consistently the heaviest one-thousand grain weight of maize in both years, significantly higher than those with green or black in 2017. The superior grain weight attained in the white polyethylene treated plots could be attributed to better weed control, thereby giving the maize crop better access to nutrient and water absorption as well as trapping solar radiation for assimilates production and partitioning into the sink (seed). This finding agrees with the report of Streck *et al.* (1995) who obtained highest tomato yield from plots under white compared to opaque polyethylene mulches.

One- thousand seed weight of maize increased significantly ($p < 0.05$) with increase in soil solarization duration of above 2 weeks in both years, however mean values were statistically similar for the zero and 2- week solarization durations. The increase in maize grain weight due to soil solarization especially for 4- and 6- week periods suggests that the significant reduction in weed density and weed dry matter due to soil solarization had a significant beneficial impact on the accumulation of dry matter by the maize seeds in those treatments. Conversely, the relatively lighter maize grain weight attained in the 2- week and no-solarization treatments could be attributed to the greater weed populations and weed dry matter accumulation in these treatments, which would have impacted negatively on resource availability to the maize crop for grain filling. Interactively, solarization for 6 weeks with white polyethylene film resulted in significantly heavier 1000- grain weight than all other treatment combinations, while the lightest weights were consistently obtained from the control in both years of study. This is in agreement with Kawsar *et al*. (2011) who reported an increase in the thousand-grain weight of maize in weeded plots as compared with weedy treatments. These researchers attributed the lower grain weight in the weedy treatments to increased competition for moisture, light and nutrients, and the higher grain weight in the weed- controlled plots to better growth and development and more seed assimilates of the maize plants due to availability of more growth resources as a result of decreased competition with weeds. In the present research, weed resurgence following hand weeding in the control and the removal of the polyethylene films at 2 weeks after solarization in the 2-week solarization treatments could have resulted in critical weed competition with the maize crop, thereby affecting grain filling and weight.

Conclusions

Pre-plant soil solarization was effective in weed control and enhanced the weight of maize grains in both years of study. White polyethylene film was superior to the black and green in weed suppression and resulted to the highest grain weight of maize. Weed control effectiveness increased with increasing solarization duration with the 6- week period as the most effective. Best weed suppression and grain weight of maize were obtained from solarization for 6 weeks using white polyethylene film, and is thus recommended for maize growers in the Calabar area. The adoption of polyethylene mulching technology by maize farmers can reduce their dependence on manual labour for weed control and yield loss due to weeds in Nigeria.

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Table 4: Impact of polyethylene film colour and solarization duration on 1000- seed weight (g) of maize

Solarization Treatments		Maize 1000 - seed weight (g) 2016	2017	Mean
Polyethylene Colour				
Black		180.2	128.70	154.45
Green		186.8	128.97	157.89
White		191.4	134.20	162.80
$LSD_{(0.05)}$		NS*	1.80	NS
Solarization duration (weeks)				
0		167.8	114.14	140.97c
2		169.7	121.09	145.490c
4		195.7	135.29	165.50b
6		209.4	151.97	180.69a
$LSD_{(0.05)}$		14.12	2.08	10.44
Interaction				
Duration	Colour			
0	Black	169.1	114.51	141.81bc
	Green	174.3	112.19	143.25bc
	White	159.9	115.71	137.81c
2	Black	161.5	119.31	140.41bc
	Green	170.9	120.34	145.62bc
	White	176.7	123.65	150.18bc
4	Black	198.0	134.28	166.12abc
	Green	198.2	133.65	165.93abc
	White	196.8	137.94	167.37abc
6	Black	192.3	146.71	169.51abc
	Green	203.9	149.70	176.80ab
	White	232.1	159.51	195.81a
$LSD_{(0.05)}$		23.99	3.60	36.19

Table 1: Weed density (no m^{-2}) as influenced by polyethylene film colour and pre-planting soil solarization duration in maize field

Solarization Treatments		Weed density (no m^{-2}) 2016 Weeks after planting 3	6	9	Total	2017 Weeks after planting 3	6	9	Total	Combined Mean
Polyethylene Colour										
Black		25.40	37.58	97.18	160.16	23.75	22.17	25.93	71.84a	115.90
Green		22.03	33.73	96.08	151.84	19.93	22.08	26.85	68.86a	110.40
White		26.33	33.10	87.25	146.68	16.18	17.59	25.05	58.82b	102.70
$LSD_{(0.05)}$		NS*	NS	NS	7.72	6.25	4.14	NS	5.39	NS
Solarization duration (Weeks)										
0		41.00	59.90	132.60	233.5	33.10	34.00	38.63	105.73	179.20
2		37.90	52.10	114.90	204.9	20.47	21.33	28.57	70.37	124.60
4		15.30	24.80	76.60	116.7	15.57	16.56	22.90	55.02	73.00
6		8.10	18.40	50.00	76.5	10.67	10.56	13.67	34.89	34.00
$LSD_{(0.05)}$		9.95	17.70	17.98	6.69	7.52	4.48	6.43	6.22	35.22
Interaction										
Duration (weeks)	Colour									
0	Black	40.30	63.70	130.70	234.7	36.30	34.67	35.30	106.27	170.50
	Green	29.00	50.60	130.30	209.90	33.30	37.00	38.30	108.60	159.30
	White	53.70	65.70	136.70	256.10	29.70	30.33	42.30	102.33	179.23
2	Black	28.00	37.30	112.70	178.00	24.00	23.00	28.70	75.70	126.90
	Green	32.70	36.30	116.00	185.00	19.70	22.33	28.70	70.73	127.90
	White	33.00	34.30	116.00	183.30	17.70	18.67	28.30	64.67	124.00
4	Black	15.00	28.00	81.30	124.30	19.00	17.67	24.70	61.37	92.30
	Green	17.70	28.70	78.00	124.40	15.70	17.33	24.70	57.73	91.07
	White	13.30	17.70	70.30	101.30	12.00	14.67	19.30	45.97	73.64
6	Black	18.30	21.30	64.00	103.6	15.70	13.33	15.00	44.03	73.82
	Green	8.70	19.30	60.00	88.00	11.00	11.67	15.70	38.37	63.19
	White	5.30	14.70	26.00	46.00	5.30	6.67	10.30	22.27	34.14
$LSD_{(0.05)}$		19.89	32.58	32.51	13.37	13.03	8.28	11.13	10.78	61.01

*NS = Not significant

Table 2: Effects of polyethylene film colour and pre-planting soil solarization duration on weed morphology in maize field

		Broad leaves (no m^{-2})			Grasses (no m^{-2})			Sedges (no m^{-2})		
Solarization Treatments		**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**	**2016**	**2017**	**Mean**
Polyethylene Colour										
Black		60.94	49.59	55.27	38.13	10.16	25.20	61.60	12.10	36.85
Green		61.98	46.16	54.07	34.50	9.25	21.90	63.44	13.25	38.35
White		59.45	41.91	50.70	29.95	6.59	18.30	61.74	10.41	36.08
$LSD_{(0.05)}$		1.10	0.52	4.37	1.08	0.46	1.71	1.39	0.50	2.02
Solarization duration (Weeks)										
0		93.83	77.45	85.64	47.80	10.66	29.23	112.95	17.78	65.37
2		79.04	49.22	64.13	44.38	11.68	28.03	75.70	15.80	45.75
4		58.44	34.05	46.25	25.23	9.23	17.23	32.92	11.21	22.07
6		11.44	23.11	17.28	19.26	6.08	12.67	23.45	6.89	15.17
$LSD_{(0.05)}$		1.27	0.61	5.04	2.29	0.53	1.97	3.60	0.58	2.33
Interaction Duration (Weeks)										
0	Black	89.37	77.03	83.20	50.00	13.67	31.80	113.53	15.67	64.60
	Green	90.40	81.33	85.90	49.30	8.99	29.10	114.63	18.33	66.48
	White	101.72	74.00	87.90	44.33	9.34	26.80	110.72	19.33	65.03
2	Black	74.06	55.67	64.90	48.76	9.33	33.30	73.40	10.67	42.04
	Green	81.33	43.67	62.50	41.97	10.33	26.10	75.12	15.33	45.23
	White	81.73	48.67	65.20	42.40	6.99	24.70	90.59	9.34	49.97
4	Black	61.67	38.00	49.85	29.38	10.01	19.70	33.06	13.33	23.20
	Green	66.04	31.66	48.90	22.33	12.33	3.41	35.17	12	23.59
	White	47.64	32.33	40.00	23.99	5.33	14.70	30.53	8.33	19.43
6	Black	18.67	27.67	23.17	24.33	7.66	16.00	26.41	8.67	17.54
	Green	8.99	29.00	19.00	24.38	5.33	15.10	28.83	7.33	18.08
	White	6.67	12.66	9.67	9.05	4.66	6.90	15.10	4.66	9.88
	$LSD_{(0.05)}$	2.21	1.05	8.74	3.96	0.93	3.41	2.27	1.01	4.03

Table 3: Weed dry matter as influenced by polyethylene film colour and pre- planting soil solarization duration in maize field

Solarization Treatments		**Weed dry matter (g/m²)**								
		2016				**2017**				**Combined Mean**
		Weeks after sowing				**Weeks after sowing**				
Polyethylene Colour		**3**	**6**	**9**	**Total**	**3**	**6**	**9**	**Total**	
Black		5.89	8.75	21.28	35.92	3.81	5.41	7.42	16.64	26.30
Green		4.95	8.31	21.79	35.05	3.73	5.09	7.11	15.93	25.50
White		5.18	7.69	19.35	32.22	3.30	4.30	6.01	13.61	22.90
$LSD_{(0.05)}$		NS*	NS	NS	0.44	NS	0.73	0.44	0.43	NS
Duration (Weeks)										
0		9.07	12.45	32.29	53.81	6.18	7.89	10.58	24.65	39.20a
2		8.79	12.08	27.67	48.54	3.71	5.05	7.13	15.89	32.20a
4		2.05	4.29	14.00	20.34	2.73	3.90	5.41	12.04	16.20b
6		1.45	4.19	9.26	14.90	1.83	2.89	4.24	8.96	11.90b
$LSD_{(0.05)}$		3.02	3.9	5.79	0.51	0.71	0.84	0.51	0.50	8.38
Interaction										
Duration (Weeks)	Colour									
0	Black	9.69	12.76	31.87	54.32	6.03	8.09	10.75	24.87	39.60a
	Green	8.30	12.11	32.81	53.22	6.30	7.77	10.47	24.54	38.88a
	White	9.21	12.47	32.19	53.87	6.21	7.81	10.52	24.54	39.21a
2	Black	8.98	12.48	28.13	49.59	4.26	5.94	7.79	17.99	33.71a
	Green	8.63	11.90	29.29	49.82	3.43	4.96	6.96	15.31	32.57a
	White	8.76	11.85	25.60	46.21	3.43	4.25	6.65	14.33	30.27ab
4	Black	2.34	4.76	14.07	21.17	2.67	4.22	6.07	12.96	17.07bc
	Green	1.71	4.08	14.36	20.15	3.02	4.08	6.03	13.13	16.64bc
	White	2.13	4.02	13.56	19.71	2.49	3.38	4.15	10.02	14.87c
6	Black	2.58	5.01	11.05	18.64	2.28	3.37	5.07	10.72	14.68c
	Green	1.15	5.13	10.71	16.99	2.15	3.53	4.96	10.64	13.82c
	White	0.62	2.43	6.03	9.08	1.06	1.76	2.70	5.52	7.30c
$LSD_{(0.05)}$		5.48	6.17	10.37	0.89	1.22	1.46	0..89	0.86	14.51

*NS = Not significant