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Efficacy of soil solarization on the control of root-knot nematodes infecting eggplant (*Solanum melongena*) in Plateau State

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The efficacy of soil solarization was tested for the control of root-knot nematodes in Foron District of Barkin Ladi Local Government Area of Plateau State using three commercially available cultivars of eggplant (*Solanum melongena*) namely: Yallo Bello, Chida Masoyi and Farin Yallo. Two levels of soil solarization based on time of exposure namely: Four weeks, five weeks and a control were employed. Soil temperature for each bed was taken weekly in the morning and afternoon using soil thermometer at different soil depths. Results revealed that growth and yield parameters of eggplant namely plant height, stem girth, number of leaves, number of fruits, and fresh weight of fruits grown in solarized soil were significantly higher than those of the control (unsolarized soil) at 0.05 level of probability. More galls were seen on the roots of unsolarized plants, followed by the four weeks and the five weeks' solarization had the least. This is indicative of the effectiveness of soil solarization in the control of nematodes, especially for longer periods of solarization. The three cultivars of eggplant did not differ with reference to soil solarization. Soil solarization could be an effective tool for nematode control on the Plateau since it is cheaper, has no phytotoxic effects, and does not constitute environmental and health hazards. The technique can be improved with more investigation's on length of exposure and improvement of the durability of the polyethylene film. Continuous use of these polyethylene films will reduce the cost of buying the polyethylene films repeatedly when it is needed.

Key words: Soil, Solarization, *Solanum melongena*, nematodes, efficacy.

INTRODUCTION

Solanum melongena, popularly called "eggplant" (family *Solanaceae*) a plant of enormous importance, ranking third out of five useful vegetables (Choudhary and Gaur, 2009). It is mainly used as a food crop and also has various medicinal uses that make it a valuable addition to the diet (Daunay and Janick, 2007). Despite the importance of this crop, there are various production constraints, which include diseases and pests such as

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nematodes, slugs, snails and caterpillars (Choudhary and Gaur, 2009; Stirling, 2014).

Plant-parasitic nematodes are by nature organisms that impair crop health and reduce their yields and their presence has been found to cause profound metabolic disturbance throughout the plant (Stirling, 2014). Nematodes, apart from being destructive, predispose plants to other pathogens and serve as carriers of other pathogens (Stirling, 2014). This has been a major cause for concern to farmers because they cause a series of losses, particularly in plant yields. Therefore, there is the need to control this “cankerworm” eating deep into the fabrics of crop production. There are various ways of controlling nematode infection, including chemical, cultural, biological, physical, and genetic methods (Stirling, 2014).

Chemical control is reported to be a very effective method for controlling nematodes however, it has its tolls on the environment and can constitute health hazard (Aktar et al., 2009; Stirling, 2014). It is also very expensive and mainly used for crops of very high economic value that can produce more than enough yields to upset the cost of control (Stirling, 2014), thus there is the need to investigate soil solarization as a physical method of controlling nematodes.

Soil solarization is the application of soil mulch (polyethene) to trap solar energy in order to increase soil temperature to levels that are lethal to microorganisms that cause diseases to crops of economic importance (McSorley et al., 2006). The principle of soil solarization is accomplished by manipulating the energy balance of the soil. This energy balance depends on the direction and magnitude of the net heat exchange between the soil and the atmosphere. As the soil is exposed to solar radiation, it accumulated heat throughout the day (Hasing et al., 2004). Soil temperatures are maintained within a range that is determined by conditions such as climate and soil characteristic. It is important to note that the mulch used during solarization also reduces heat loss without significantly interfering with the absorption of solar energy. This results in increased soil temperature.

Soil solarization was initially pioneered in countries of the Middle East where intense solar radiation and high temperatures are appropriate for solar heating (Hasing et al., 2004). It has been known to affect not only soil-borne pathogens but also other organisms and abiotic factors that indirectly affect plant development and growth (Hasing et al., 2004). There is a scarcity of information on the efficacy of soil solarization in the control of plant-parasitic nematodes of crop plants in Nigeria even when Nigeria is a tropical country with abundant sunlight. This is a great potential for effective nematode control to be achieved by this method. It is against this background that the present investigation has been designed to assess the effects of soil solarization for the control of nematodes infecting eggplant and to determine the least time of exposure that is most effective for soil solarization.

MATERIALS AND METHODS

Study area

This research was conducted in Foron District of Barkin Ladi Local Government Area of Plateau State, Nigeria.

Cultivars of eggplant

Three cultivars of eggplant namely, “Yallo Bello”, “Chida Masoyi” and “Farin Yallo” were used in this investigation. The seeds of these three cultivars were collected from local farmers.

Research design

A complete randomized block design was used in assigning treatments and cultivars to the various plots and was replicated 72 times. Analysis of variance was done using SPSS version 23.0 (IBM SPSS Statistic, Version 23.0. Armonk, NY: IBM Corp).

Collection of soil samples

Soil samples from root rhizosphere were randomly collected into well-labelled polyethylene bags from different parts of the farm using a hand trowel. These soil samples were brought to the Botany Laboratory, University of Jos and processed for nematode extraction. The modified Baermann funnel method was employed for this extraction (Hamilton et al., 2009; Sato et al., 2009). The nematode populations were estimated per gram of soil and average counts from 1 ml of the homogenized extract of 50 g of the soil sample.

Estimation of nematode population before planting

This was done by counting the number of nematodes in 1 ml of the homogenized suspension under a binocular research light microscope at x40 magnification. An average of two root-knot nematodes was found in 1 ml of the homogenized suspension from 50 g of soil, which approximates 50 nematodes in 250 g of the soil. Therefore, this implies that for every 250 g of soil from the experimental site, there were 50 nematodes.

50 g of soil ----- 1 ml ----- 2 nematodes
250 g of soil ----5 ml ----- 50 nematodes

Nursery preparation

Steam sterilization was done between 70 and 100°C soil and cow dung in the ratio 3:3:1 of cow dung, sharp sand and top soil, respectively. This was to kill soil pests including nematodes and filled into three wooden trays. Seeds of three cultivars of eggplant that were previously soaked for four days and allowed to drain were then broadcasted on the soil and a garden fork was used to mix up the seeds and the soil.

Preparation of the beds for transplanting

Beds were raised to about 10 inches and mulched with a black polyethylene film measuring 1.5 × 1.5 m wide and 38 µm thick. These beds were kept wet and mulched. Wetting of the beds continued once every week to keep the soil moist and aid heat conduction within the soil for the period of solarization. These

Table 1. Root galls rating scale.

Number of galls	Root index	Resistance rating
0	0	immune
1-2	1	Resistant
3-10	2	Moderately resistant
11-30	3	Moderately susceptible
31-100	4	Susceptible
>100	5	Highly susceptible

Taylor and Sasser (1978).

polyethylene films were held firmly in place using stones. Soil temperature was monitored once every week at 10: 00 am and 4: 00 pm at 5, 10 and 20 cm depth for each bed. This was done for both solarized and unsolarized treatments throughout the period of solarization. The minimum and maximum temperatures for each week were recorded.

Soil solarization

Solarization films were installed for four- and five-weeks' treatments. The soil was kept clean and allowed to stand for this period of treatment. The unsolarized soil (control) was also kept clean but not moistened for the period of treatment. After four and five weeks of solarization, seedlings from the nursery were transplanted and solarization was discontinued. Fertilizer was applied at 168/224 kg hectare of Urea and Nitrogen, Phosphorus and Potassium (NPK). Irrigation was done to sustain seedlings for the period when there was no rainfall and discontinued at the start of the rains. Dichlorvos 76% EC, a pesticide, was applied to prevent shoot pests from perching on the leaves since the start of planting was the peak of hot and conductive weather for these pests. Planting was done at 35 × 35 cm between and within rows. Eggplants which were about 80% matured were harvested after three months of planting. These plants were in the field for 13 weeks after transplanting

Growth and yield parameters

Plant growth and yield parameters measured include plant height, stem girth, number of leaves, number of fruits, and fresh weight of fruits.

Estimation of the nematode population

The nematode populations in the soil were estimated at the end of the research and analysed statistically. Fifty soil samples were taken from each of the 36 plots, placed in well- labelled polyethene polyethylene bags, and brought to the laboratory. Each of the plots represented the four and five weeks of treatment, their control (unsolarized) and their replications. The modified Baermann funnel was used after which the set-ups were dislodged and the nematode suspension was homogenized and average counts of nematodes per ml were done for the estimation of the nematode populations in the soil.

Observation of plants for nematode infection

Roots of the 72 eggplants were examined for galls. When galls were seen, they were counted, recorded and the gall indexes were calculated for each treatment. Root galls were rated according to the Taylor and Sasser (1978) scale, as shown in Table 1. Gall indexes were calculated by first placing each plant in a class and the average gall indexes of the plants was calculated by multiplying the class number by the number of plants in each class and the products were summed. The sum was then divided by the total number of plants for an average to determine the gall indexes.

RESULTS

Soil temperature was generally higher in solarized soil compared to unsolarized soil. These temperatures also varied with soil depth with the highest at the 20 cm depth and lowest at the 5 cm depth. Soil temperatures were also higher in the afternoon than in the mornings (Table 2). The results of this investigation revealed that the two levels of solarization, namely four and five weeks, generally resulted in higher mean plant height compared to the control (unsolarized). The plant height of eggplants grown in solarized soil for five weeks was significantly higher than those grown in four weeks solarized soil ($p<0.05$). The average plant height of plants grown on four weeks solarized soils were higher than those grown in unsolarized soil (control) but did not differ significantly ($p<0.05$) (Table 3).

Table 4 shows that the mean stem girths of plants grown in solarized soil were significantly higher than those grown in unsolarized soil at five and four weeks ($p<0.05$). The mean number of leaves per plant was generally higher for plants grown in solarized soil as compared to those grown in unsolarized soil (control). Plants grown in soil solarized for five weeks had a significantly higher number of leaves compared to those of plants grown in the control treatment. Although the number of leaves of plants grown in soil solarized for four weeks averaged higher than those grown in the control treatment, there were significant differences in the number of leaves per plant. The mean number of leaves per plant did not vary between the cultivars at $p<0.05$ (Table 5).

Table 6 shows the mean number of fruits per plant was generally higher in plants grown in solarized soil compared to those grown in unsolarized (control) soil.

Table 2. Average temperatures of solarized and unsolarized soil at three soil depths for morning and afternoon.

Time	Unsolarized			Solarized		
	5 cm	10 cm	20 cm	5 cm	10 cm	20cm
WK 1. 10.00am	26.62	28.22	28.32	34.62	35.83	35.89
4.00pm	28.81	29.33	29.64	38.57	39.65	39.75
WK 2. 10.00am	28.01	27.72	29.91	35.53	36.61	36.69
4.00pm	29.02	29.97	31.00	39.83	40.88	40.81
WK 3. 10.00am	28.32	29.99	30.00	34.55	35.65	35.70
4.00pm	31.62	31.32	33.91	38.54	40.67	40.77
WK 4. 10.00am	28.72	29.67	30.07	36.55	37.41	37.32
4.00pm	32.33	31.66	33.99	39.59	41.59	41.61
WK 5. 10.00am	29.91	30.79	30.11	38.32	39.51	39.61
4.00pm	33.07	33.33	33.00	41.27	42.07	42.11

Table 3. Mean plant height per plant of three cultivars of eggplant grown in solarized and unsolarized soil (control).

Solarization	Cultivars		
	Yallo Bello	Chida Masoyi	Farin Yallo
Four weeks	53.25^{b}	52.26^{ab}	44.08^{b}
Five weeks	67.21^{a}	63.10^{a}	63.59^{a}
Unsolarized control	42.14^{b}	41.66^{b}	35.53^{b}

Means with the different superscripts within the same column are significantly different at p<0.05 (LSD 11.29).

Table 4. Mean stem girth per plant of three cultivars of eggplant grown in solarized and unsolarized soil (control).

Solarization	Cultivars		
	Yallo Bello	Chida Masoyi	Farin Yallo
Four Weeks	3.21^{b}	3.20^{b}	3.10^{b}
Five Weeks	4.05^{a}	4.04^{a}	4.04^{a}
Unsolarized Control	1.41^{c}	1.31^{c}	1.20^{c}

Means with the different superscripts within the same column are significantly different at p<0.05 (LSD 0.33).

Plants grown for five weeks in solarized soil had significantly higher (p<0.05) mean number of fruits than the control treatment. The number of fruits on plants grown in soil solarized for four weeks did not differ significantly from the control treatment (p<0.05). The values for mean fresh weight of fruits are presented in Table 7. The mean fresh weight of fruits per plant was generally higher in plants grown in solarized soil compared to those grown in unsolarized (control) soil. Plants grown in solarized soil for five weeks had significantly higher mean dry weight of fruits than the control treatment (p<0.05). The mean fresh weight of fruits grown in soil solarized for four weeks did not differ significantly from the control treatment at p<0.05.

Table 8 shows the estimated number of nematodes per 50 g of soil after harvest at the different time intervals of solarization and the unsolarized (control). This was to ascertain if the population of nematodes reduced with solarization or the increase in growth and yield parameters just favoured solarized soil than the unsolarized control. Nematode populations were seen to be significantly higher and different for the control

Table 5. Mean number of leaves per plant of three cultivars of eggplant grown in solarized and unsolarized soil (control).

Solarization	Cultivars		
	Yallo Bello	Chida Masoyi	Farin Yallo
Four weeks	89.67[ab]	84.33[a]	75.67[ab]
Five weeks	104.00[a]	91.00[a]	98.00[a]
Unsolarized control	58.00[b]	68.33[a]	52.67[b]

Means with the different superscripts within the same column are significantly different at $p<0.05$ (LSD 35.09).

Table 6. Mean number of fruits per plant of three cultivars of eggplant grown in solarized and unsolarized soil (control).

Solarization	Cultivars		
	Yallo Bello	Chida Masoyi	Farin Yallo
Four weeks	14.00[ab]	15.67[ab]	12.67[a]
Five weeks	19.00[a]	20.33[a]	15.00[a]
Unsolarized control	11.67[b]	10.33[b]	9.67[a]

Means with the different superscripts within the same column are significantly different at $p<0.05$ (LSD 6.94).

(unsolarized) and the four weeks' treatment at $p<0.05$. Root gall indices differed amongst plants grown in solarized soil as compared to those grown in the unsolarized soil. The root gall index was 1.29≈1.3.

DISCUSSION

The results of this investigation revealed that there was an increase in temperature of solarized soil compared to the unsolarized soil. This agrees with the earlier report of Hasing et al. (2004) who observed a marked increase in the temperatures of solarized soil as compared to the unsolarized soil. This increase in the temperature may be attributed to the fact that the polyethylene films used as mulch during soil solarization trapped heat. The increase in soil temperature can also be associated with limited air circulation that consequently led to limited energy lost through evaporation, which is recovered as water condenses on the mulch thereby increasing the soil temperature via modification of optical characteristics of the water (Stirling, 2014).

Soil temperature also increased in the afternoon (4:00 pm) compared to the morning (10:00 am). This is in line with reports from Hasing et al. (2004) and Stirling (2014), that as the soil is mulched and exposed to solar radiation, it accumulates heat throughout the day because the mulch reduced heat loss. The temperature was also seen to increase with soil depth in the afternoon. Hasing et al. (2004) reported that peak temperature is normally experienced in the afternoon as soil depth increase.

Nematode populations were seen to be significantly higher and different for the control (unsolarized) compared to the four weeks' treatment. The estimated number of nematodes per 50 g of soil after harvest at the different time intervals of solarization and unsolarized (control) was carried out to ascertain if the population of nematode reduced with solarization or the increase in growth and yield parameters just favoured solarized soil than the unsolarized. Nematode population has been reported to reduce with increase time of solarization (Bacha et al., 2007).

The mean plant height per plant for plants grown in the three levels of solarization averaged higher than those on unsolarized soil (control). The five weeks' soil solarization treatment was more significant in nematode control than the four weeks ($p<0.05$) indicative by stem girth, number of fruits, number of leaves, fresh weight of fruits. Bacha et al. (2007) reported a reduced nematode population with increase time of solarization, which might have favoured the growth and yield parameters of eggplant. Soil solarization is also reported to improve soil characteristics that can influence crop performance such as nutrient concentration (Mauromicale et al., 2010).

Nematode populations were seen to have reduced with increased time of solarization. Soil solarization has been reported to reduce the nematode population between 37-100% (Candido et al., 2008). There is also a report that soil solarization reduced soil pest including nematodes, weed presence, and enhance soil chemical and physical properties, which in turn increases yield (Bacha et al., 2007).

Table 7. Mean fresh weight of fruits per plant of three cultivars of eggplant grown in solarized and unsolarized soil (control) at two different time intervals.

Solarization	Cultivars		
	Yallo Bello	**Chida Masoyi**	**Farin Yallo**
Four weeks	9.42^{ab}	8.78^{b}	8.61^{ab}
Five weeks	13.51^{a}	17.33^{a}	12.72^{a}
Unsolarized control	7.28^{b}	6.62^{b}	6.70^{b}

Means with the different superscripts within the same column are significantly different at p<0.05 (LSD 4.74).

Table 8. Estimation of nematode population eggplant grown in solarized and unsolarized soil (control) at two different time intervals.

Solarization	Cultivars		
	Yallo Bello	**Chida Masoyi**	**Farin Yallo**
Four weeks	3.33^{b}	3.67^{b}	2.33^{b}
Five weeks	2.00^{b}	1.67^{c}	1.67^{b}
Unsolarized control	5.33^{a}	4.00^{a}	4.33^{a}

Means with the different superscripts within the same column are significantly different at p<0.05 (LSD 1.37).

Root gall indices differed amongst plants grown on solarized soil as compared to those in the unsolarized soil. The root gall index of the plants was 1.29≈1.3 meaning the gall indices are greater than one but less than two which could imply that the plant cultivars used might be resistant.

In conclusion, solarization led to lower nematode population with consequently better plant performance than non-solarized treatment and the cultivars under investigations did not respond differently to solarization. Therefore, soil solarization could be an effective means of nematode control in the soil. It is cheaper and less stressful compared to other methods of nematode control. Besides, it is scientific and its adoption does not require much expertise. Solarization has no phytotoxic effects and does not constitute any environmental and health hazards.

Soil solarization can be improved with more investigations. Since mulch pigmentation plays an important role in the efficacy of the mulch, it is therefore recommended that varying thickness of the polyethylene films should be investigated for efficacy in soil solarization for the control of nematodes to detect the best, or more effective, polyethylene films. Also, checking and improving the durability of this polyethylene is essential to ensure the continuous use of these polyethylene films because these plastic films degrade actively when exposed to ultraviolet radiation. Ultraviolet radiation is a component of natural light and thereby reduces the cost of buying the plastic films repeatedly when needed. Research should also be done on the economics of the technology to compare the cost of solarization to the market value of the crops produced. Lastly, solarization can also be integrated with fumigation in nematode control to get the best results.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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