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Treatment of irrigation water infested with nematodes using a solar photoreactor

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ABSTRACT

The objective of this study was to assess the efficacy of the disinfection of irrigation water loaded with the plant-parasitic nematode *Meloidogyne incognita* using a solar photoreactor. The photoreactor was comprised of a compound parabolic concentrator and a disinfection chamber made of borosilicate glass where a static mixer coated or uncoated with TiO_2 was installed. Water loaded with *M. incognita* was exposed to solar radiation within the reactor and recirculated while accumulated ultraviolet (UV) energy was registered. It was determined that an accumulated UV solar energy of 72 kJ/L inhibited the motility of juveniles while accumulated energy of 215 kJ/L was necessary to inhibit the egg hatching. Plants of lettuce irrigated with the treated water showed significantly less nodulation, higher air-dry weight and root dry-weight compared with the control group. No significant differences were found using the static mixer either coated with TiO_2 or uncoated.

Keywords: Solar disinfection; *Meloidogyne incognita*; Nematode; Hydroponics

1. Introduction

The limited availability of water resources on a global scale, together with the projections of climate change, allows us to anticipate increases in temperatures, which, along with urbanization, will bring about increased demands for irrigation water. Additionally, agricultural activities for local populations as well as exports increase water scarcity [1]. This requires the use of waste/recycled water carrying phytopathogens, whose final destination is the crops irrigated with this water. The use of waste/recycled water poses a significant risk to crop health because irrigation depends, and will increasingly depend, on the use of waste/recycled water. In some regions, water scarcity has led to the recapture of surface runoff water or leached water from agricultural fields to prevent groundwater and surface water pollution caused by the presence of nitrogen, phosphorus, and pesticides as well as to improve the efficiency of irrigation [2,3]. Even if the water source is free of phytopathogens, they may enter the water through contact with soil or plant material via multiple places along the distribution route [4]. Using water loaded with nematodes for irrigation increases the

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nematode population even in fumigated soils, whereas using clean well water for irrigation does not [5]. The presence of plant-parasitic nematodes in the treated water of some plants demonstrates the need to include control measures to regulate the use in irrigation [6]. The individual assessment of each case and the development of customized solutions are required to lower the concentration of phytopathogens, such as nematodes [7], and ultraviolet (UV) radiation is included among these solutions [8]. The inactivation of both juvenile and adult nematodes using UV radiation as well as the temperature has been demonstrated in experiments using the free-living nematode *Rhabditidae* [9]. The use of heterogeneous catalysis (TiO_2/UV) has also been suggested [10] to disinfect plant pathogens because it generates reactive oxygen species the could improve the solar treatment.

In our country, the nematode *Meloidogyne incognita* is considered to be one of the five pathogens that affect the principal crops [11] by impairing their ability to absorb water and soil nutrients [12], *M. incognita* is among the most damaging root-knot species whose infection reduces shoot and root lengths and fresh and dry weights, thereby forcing farmers to use nematicides. For example, infestation problems have been reported in passion fruit crops, vineyards, red globe grapes, etc. in the Coastal, Andean or Amazonian areas of Peru.

The present study aims to evaluate the efficacy of the treatment of irrigation water using solar radiation and also evaluating the effects of adding TiO_2 as a means to enhance disinfection. Here we describe the photoreactor developed and constructed, the experimental methodology used, and the experimental as well the statistical results obtained.

2. Materials and methods

2.1. Disinfection photoreactor

The solar photoreactor used in this study comprises a disinfection chamber, a truncated compound parabolic concentrator (TCPC) and a hydraulic installation. Fig. 1 shows a schematic diagram of this reactor.

The disinfection chamber is made of transparent borosilicate glass tubing with an internal diameter of 2.6 cm and a length of 107 cm. It has natural rubber plugs at both ends, which have a central hole through which hose connectors have been attached. The hose used in the peristaltic pump is made of Tygon®, while the hoses used in the rest of the reactor are made of nylon. Within the disinfection chamber there is a static mixer made of 1 mm thick 316 L stainless steel (Fig. 2) uncoated or coated with TiO_2 nanoparticles; TiO_2 coating allows for hydroxyl radicals ($OH^{\cdot}$) responsible for disinfection to be generated after receiving UV radiation [13] and have been proposed as a method of inactivation of a broad range of plant pathogens present in water (Polo-López et al. [10]).

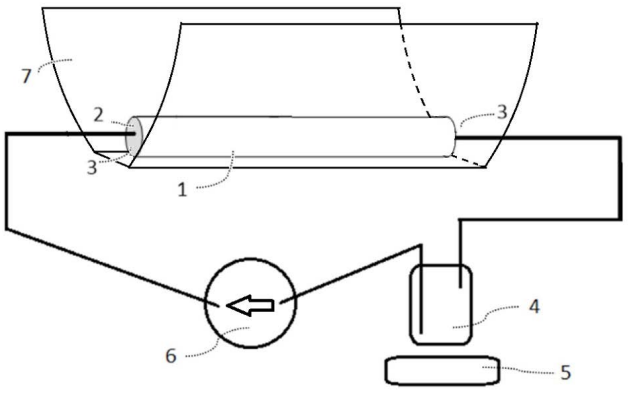

Fig. 1. Solar photocatalytic reactor. 1, Disinfection chamber; 2, Air-tight sealing lid; 3, Water inlet and outlet ports; 4, Container with a temperature sensor; 5, Magnetic stirrer; 6, Peristaltic pump; 7, Truncated compound parabolic concentrator.

The solar concentrator is 120 cm long, with a 4 cm wide base and an upper opening measuring 28 cm. Its curved profiles were 3D printed, and its reflective surfaces consist of high-reflectance anodized aluminum, 0.4 mm thick (Figs. 3a and b). The curvature followed by the profile of the TCPC corresponds to Eq. (1) proposed by Tapia and del Río [14], as shown below:

$$z = 2L - \left[\left(\frac{L}{a+a'}\right)\left(|x|+a'\right)\right] - 2\frac{a\left(a+a'\right)}{a'}\sqrt{1-\left[\frac{|x|+a'}{a+a'}\right]} \quad (1)$$

where a = 11.75 cm, a' = 2.35 cm, and L = 37.87 cm (Fig. 3c). These values correspond to the dimensions of the disinfection chamber that must be fixed on the TCPC base. The value of the optical power of concentration was 4.6. However, based on direct experimental measurements, this value was 3.3 on sunny days and 1.5 on cloudy days.

The hydraulic system comprises a Lead Fluid BT100S peristaltic pump with YZ15 head, a 1 L Erlenmeyer, and a CAT M5 magnetic stirrer. The total UV energy received by a unit of volume (Q_{UV}) was calculated according to the following equation:

$$Q_{UV} = \sum_n \overline{UV}_{n-1}\frac{A_r}{V_t}\left(t_n - t_{n-1}\right) \quad (2)$$

where t_n is the experimental time for n-sample, $\overline{UV}_{n-1}$ is the average solar UV radiation measured during the period $(t_n - t_{n-1})$, A_r is the illuminated surface, and V_t the total water volume [15].

The photoreactor was built at the University of Lima (Lima, Peru) and was installed in an area that was previously adapted within the Hydroponics and Mineral Nutrition Research Center (CIHNM, for its Spanish acronym) of the National Agrarian University-La Molina (Fig. 4).

Fig. 2. Right: Photograph of the disinfection chamber; 1, transparent borosilicate glass tubing, 107 cm long, with an internal diameter of 2.6 cm; 2, static stainless-steel mixer; 3, rubber stopper with the central orifice. Left: Photograph of the static mixer; each one is 34 cm long and 2.5 cm wide; therefore, it is necessary to join three of them, one after the other, within the disinfection chamber.

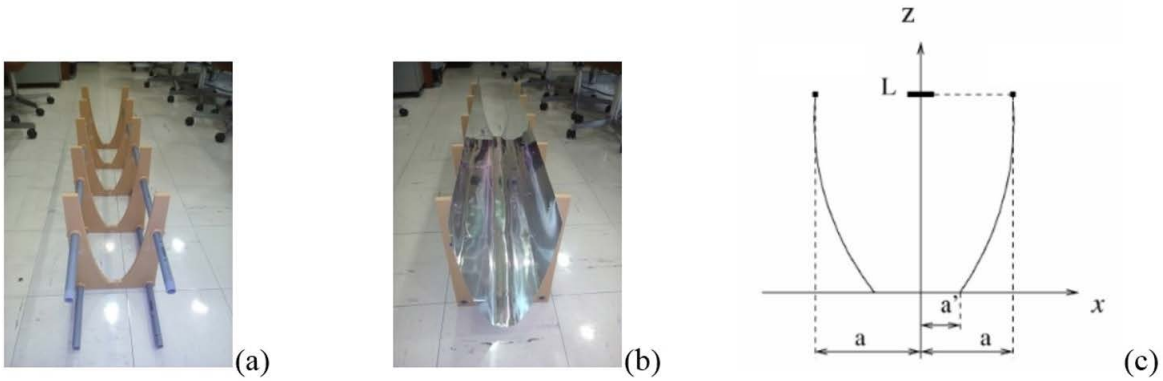

Fig. 3. (a) Photographs of the structure (with 3D-printed profiles and PVC pipes), (b) TCPC used in the solar photoreactor, and (c) dimensions of TCPC

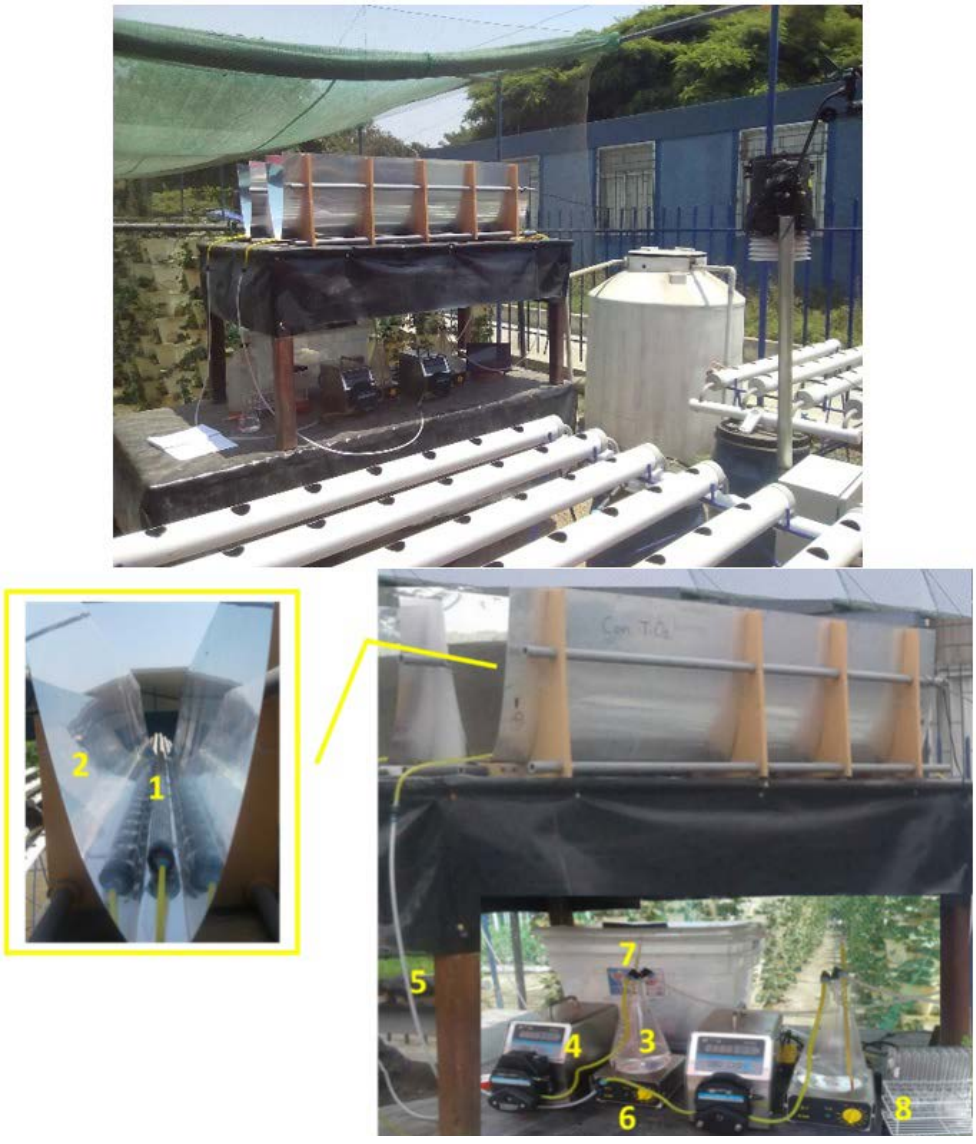

Fig. 4. Left: Photograph of the solar photocatalytic reactor. Center: 1, TCPC; 2, disinfection chamber containing the static mixer. Right: 3, 1 L Erlenmeyer flask; 4, peristaltic pump; 5, connection hoses; 6, magnetic stirrer; 7, mercury thermometer (0°C–150°C); 8, 16 × 100 mm test tubes used for sample collection.

Fig. 4 includes photographs with the main parts of the reactor and the Davis Vantage PRO 2 meteorological station that is used to record data, such as ambient temperature, UV radiation index, and total solar radiation.

2.2. Preparation of TiO_2 coating

The photocatalyst material was added and immobilized in the static mixer through the following process: washing the static mixer with detergent and rinsing with deionized water, washing in an ultrasonic bath with isopropyl alcohol and acetone for 5 min and rinsing with deionized water. Anodizing is a 4 mol/L sulfuric acid solution with an electric current intensity of 1.7 A for 20 min. Dip-coating with the TiO_2 sol (prepared using titanium isopropoxide, nitric acid, and deionized water, at pH 0.95 because a high adhesion on steel is achieved at this pH value). The dip-coating was done by immersing the static mixer in the solution for 1 min and subsequently drying at room temperature for approximately 30 min and repeated four times. The coated static-mixer was calcinated in a tubular furnace with an inert atmosphere using ultra-high purity nitrogen gas, with a ramp of 4.3°C/min, maintained at 723 K for 2 h. Finally, the piece was rinsed with deionized water.

2.3. Lettuce cultivation in a hydroponic system

For the infectivity trial in hydroponic cultures, four nutrient film technique or NFT system modules were separately built (Fig. 5). In the NFT system a thin film of a hydroponic solution -containing all the necessary nutrients- flows through PVC pipes, which contain the plant roots, there being no solid rooting medium [16]. The hydroponic nutrient solution is prepared from concentrated solutions of macronutrients (34 g $NH_4H_2PO_4$; 20.8 $Ca(NO_3)_2$ and 11 g KNO_3 per 1 L) and micronutrients (123 g $MgSO_4$; 0.12 g $CuSO_4 \cdot 5H_2O$; 62 g $MnSO_4$; 0.30 g $ZnSO_4$; 15.5 g H_3BO_3; 0.005 g $(NH_4)_2MoO_4$ and 12.5 g of sequestrene® iron chelate). Briefly, 5 ml of macronutrient solution and 2 ml of micronutrient solution were mixed for 1 L of water. Subsequently, the conductivity and pH parameters were adjusted to 1.8–2.2 mS/cm and pH to 6.0–6.5 respectively. The hydroponic nutrient solution has maintained a height of 2 cm and was recirculated using a centrifugal pump every 15 min to ensure aeration.

Fig. 5. Nutrient film technique hydroponic system; 1, pots with lettuce seedlings; 2, nutrient solution storage tank; 3, ½ HP pump; 4, recirculation hoses.

2.4. Proliferation of M. incognita populations

M. incognita eggs were obtained from galled tomato (*Lycopersicum esculentum*) plants. Roots were washed gently to avoid the detachment of egg masses and pieced in 1 cm fragments; 150 g of the fragments were mixed with 150 mL of 0.5% sodium hypochlorite solution and blended for 20 s. The solution obtained was filtered consecutively through a 200 and 25 μm mesh. Vegetal residues were collected via the first mesh; eggs were collected via the second mesh. Eggs were rinsed with tap water to cleanse the hypochlorite residues, which were collected and suspended in well water. Sixty pots with a vapor-sterilized mix of soil and sand (2:1 proportion) were prepared. Two-week-old lettuce seedlings were transferred to each pot and infected 7 d later with approximately 5,000 eggs of *M. incognita*. In the first 3 months, the populations of *M. incognita* were allowed to proliferate; next, the motility trials were performed in juveniles.

2.5. Pre-assays to verify M. incognita juveniles' viability in the treatment system

Two pre-assays were carried out to verify to what extent the working solutions and the pumping system would compromise the viability of the *M. incognita* juveniles thus confounding the results of the solar disinfection assays.

In the first pre-assay, the time (in days) in which 100 juveniles maintained motility was evaluated in three solutions: well water, irrigation water, and a hydroponic nutrient solution; one-hundred juveniles were deposited in Petri dishes containing 5 mL of one of the solutions and were evaluated at 0, 3, 6, 9 and 13 d; each treatment was replicated three times. Motility was evaluated under the stereoscopic microscope by counting the number of motile juveniles, which were then expressed as a percentage. Nematodes were defined as dead if their bodies were straight and they did not move, even after transferal to clean water [17]. The second pre-assay was conducted with the photoreactor and a peristaltic pump (Lead Fluid BT100S), where its operation was tested with residence times of 550, 100 and 66 s corresponding to flow rates of 1, 5.5, and 8.3 mL/s, respectively. The temperature was controlled between the ranges of 25°C–30°C. In these trials, two identical reactors were used, one with a TiO_2 coated static mixer and the other with an uncoated static mixer. Briefly, at 13 d after hatching, 72% of the juveniles maintained their motility in well water, 51% maintained their motility in irrigation water, and 0% maintained their motility in the nutrient solution. It has

been previously suggested that parasitic plant nematodes are unable to survive long periods of immersion in water in the absence of food and rapid gas exchange [18]. However, Moens and Hendrickx [19] showed that *M. incognita* could survive for up to 14 d in water (in vitro) and that it also had infectivity after the said period. This is consistent with the pre-assay results: after 13 d of immersion in irrigation water, 51% of the juveniles maintained their motility and, possibly, infectivity.

2.6. Disinfection trials: motility, egg hatching and infectivity on hydroponic system

Experimental trials were conducted at the facilities of CIHNM and the Physiology Laboratory of the National Agrarian University-La Molina from November 2017–July 2018 to evaluate the efficacy of the treatment of water infested with *M. incognita*.

Four trials were performed:

- Motility trial with *M. incognita* juveniles using two reactors with TiO_2 to compare the effect of solar radiation with that of shade.
- Motility trial with *M. incognita* juveniles using two reactors under solar radiation, one with TiO_2 and the other without TiO_2.
- Egg hatching trial with *M. incognita* using two reactors under solar radiation, one with TiO_2 and the other without TiO_2.
- Infectivity trial with *M. incognita* using lettuce in a hydroponic system.

2.6.1. Motility trials juveniles with M. incognita

Two identical reactors were installed with TiO_2, operating simultaneously. One was exposed to solar radiation and the other was placed in the shade, with a flow rate of 8.3 mL/s and a temperature of 25°C–30°C. Approximately 5 000 juveniles were inoculated in 1 L of well water in each of the reactor's Erlenmeyer flasks and recirculated through the reactor during a 2 h window (between 10:45 am and 12:45 pm). Sampling was conducted every 10 min up to 70 min (the time where all juveniles were still). The 5 mL samples were collected using a pipette and placed in test tubes and stored in an oxygenated and dark place for 48 h. Subsequently, the number of motile and non-motile juveniles was counted using a stereoscope. Additionally, the following parameters were recorded: temperature, UV radiation, and total radiation. This information was provided by the Davis Vantage PRO 2 Meteorological Station.

At a later time, juvenile motility was also evaluated using the same methodology described in the preceding paragraph, but comparing the effect of the coatings over the static mixer (with TiO_2 and without TiO_2) both of them under solar radiation.

2.6.2. Egg hatching trial

Eggs are the survival stage of *M. incognita* and are more resistant structures than the juveniles; therefore, it was not necessary to perform the trial under shade, that is, the test was performed with two identical reactors exposed to solar radiation, one coated with TiO_2 and the other uncoated, operating simultaneously, with a flow rate of 8.3 mL/s and a temperature of 25°C–30°C. Approximately 10,000 *M. incognita* eggs were inoculated into well water. Sampling was conducted every 20 min up to 140 min, and the percentage of *M. incognita* motile juveniles after egg hatching was recorded.

2.6.3. Infectivity trial

For the *M. incognita* infectivity test, 14 L of well water infested with approximately 140,000 eggs was treated. Two NFT hydroponic systems were installed where 25 plants of *Lactuca sativa* of the Tropicana variety, were transplanted, 2 weeks after germination, to each module. Next, the treated water was used for irrigation of one of the NFT systems while the control was irrigated with an identically infested well water without solar treatment. The volume required in each system (25 L) was completed with well water and used to irrigate the plants for 3 d. Subsequently, the nutrient solution was added to provide the necessary nutrients for the growth of lettuce, and growth was monitored for several weeks. After 45 d, root galls were rated on a 0-to-10 scale, with 0 = no galls, 1 = very few small galls, 2 = numerous small galls, 3 = numerous small galls of which some are grown together, 4 = numerous small and some big galls, 5 = 25% of roots severely galled, 6 = 50% of roots severely galled, 7 = 75% of roots severely galled, 8 = no healthy roots but plant is still green, 9 = roots rotting and plant dying, 10 = plant and roots dead [20]. Dry leaf weight, dry root weight, and a number of leaves were also evaluated.

2.7. Statistical design and analysis

Experimental data were analyzed using the *R* statistical software [21]. Experimental results are shown with graphs (Figs. 6, 7, 8 and 9) where observed values are plotted. Evaluation of significant differences between treatments is done by computing 95% confidence intervals. Because the motility curves through time or energy follow different forms, we rely on nonparametric modeling, specifically by using *B*-splines [22], to fit the models and get the confidence intervals at selected positions (Tables 1, 2 and 3). In this way, we avoid making assumptions about a functional form like a polynomial of some fixed degree. Only when a simple regression line is an appropriate model, we use that model to evaluate the significance of the treatment; in the current research, this is only the case of the evaluation of the effect of TiO_2 in the shade on the motility percentage of *M. incognita*. Comparisons of means were done using a *t*-test for all traits except for nodulation (Table 4). For this last trait, because the measurement scale is a 0 to 10 subjective ordinal scale, the Mann-Whitney non-parametric test was preferred.

3. Results and discussion

3.1. Motility test of M. incognita juveniles with TiO_2 under solar radiation and in the shade

As shown in Fig. 6, no apparent effect on juvenile motility was observed in the test conducted in the shade. When fitting a simple linear regression to these data, a non-significant

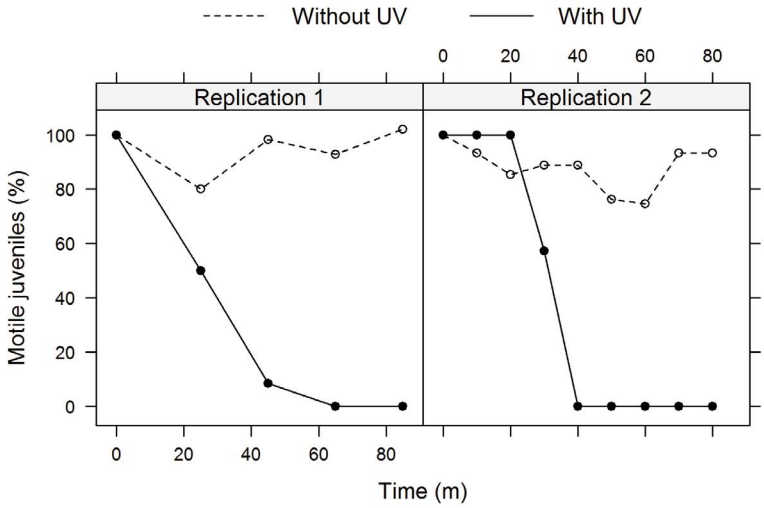

Fig. 6. Result obtained when comparing the effect of a reactor operating in the shade (without UV, with TiO_2) to one exposed to solar radiation (with UV, with TiO_2) on the motility of *Meloidogyne incognita* juveniles.

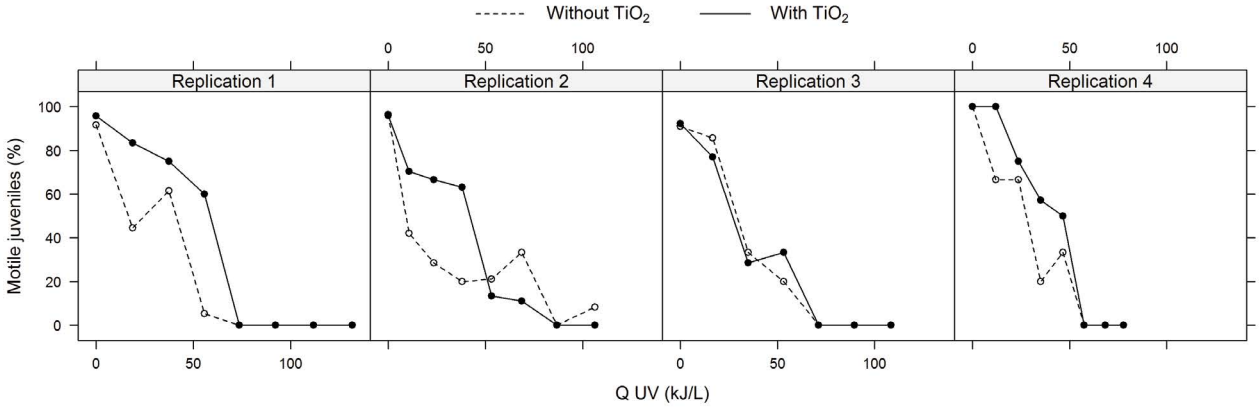

Fig. 7. Percentage of *Meloidogyne incognita* motile juveniles as a function of the Q_{UV} under solar radiation in a photoreactor with and without TiO_2.

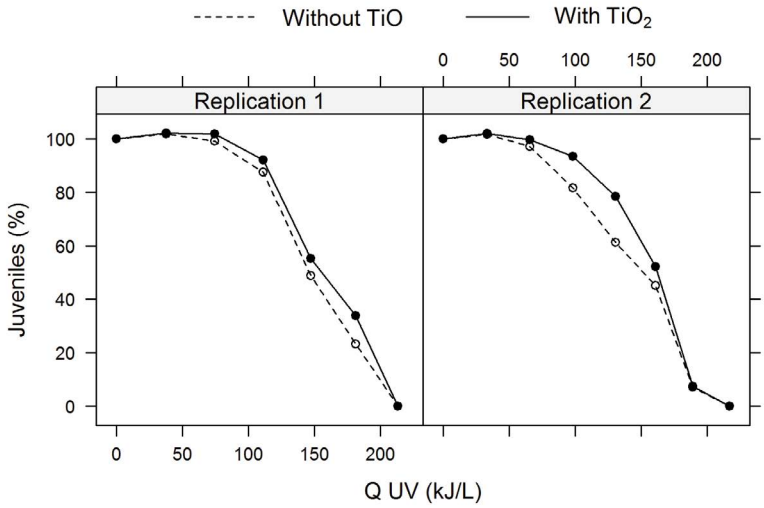

Fig. 8. Percentage of *Meloidogyne incognita* motile juveniles after egg hatching as a function of the Q_{UV} under solar radiation in a photoreactor with and without TiO_2.

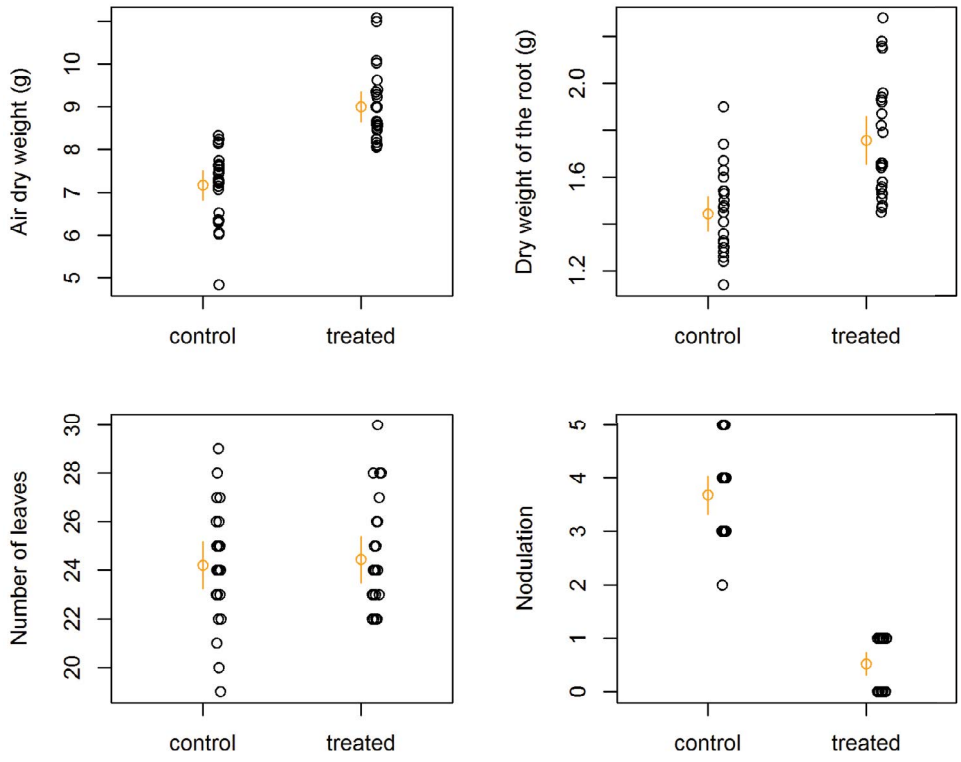

Fig. 9. Dot plots with averages and confidence levels of 95%, air-dry weight, root dry weight, number of leaves, and nodulation obtained from hydroponic lettuces grown in the NFT system.

Table 1
Estimated values and 95% confidence limits for the motility percentage of *M. incognita* at different exposition times with and without UV radiation

Time	Without UV radiation			With UV radiation		
	Estimate	Lower limit	Upper limit	Estimate	Lower limit	Upper limit
10	93.2	85.6	100.0	92.5	77.1	100.0
20	88.6	80.4	96.8	72.8	56.3	89.4
30	85.6	78.0	93.2	49.7	34.5	65.0
40	84.2	77.6	90.8	26.4	13.1	39.8
50	84.5	77.5	91.5	6.4	0.0	20.6
60	86.5	78.6	94.5	0.0	0.0	8.8

Table 2
Estimated values and 95% confidence limits for the motility percentage of *M. incognita* with UV radiation at different levels of energy with and without TiO_2

Q_{UV}	Without TiO_2			With TiO_2		
(kJ/L)	Estimate	Lower limit	Upper limit	Estimate	Lower limit	Upper limit
20	54.1	46.1	62.0	74.6	66.8	82.4
40	28.1	20.0	36.2	48.1	40.2	56.1
60	12.0	4.8	19.2	22.6	15.6	29.6
80	3.6	0.0	12.2	2.6	0.0	11.0
100	0.5	0.0	10.6	0.0	0.0	2.6

Table 3
Estimated values and 95% confidence limits for egg hatching percentage of *M. incognita* with UV radiation at different levels of energy with and without TiO_2

Q_{UV}	Without TiO_2			With TiO_2		
(kJ/L)	Estimate	Lower limit	Upper limit	Estimate	Lower limit	Upper limit
40	99.0	93.2	100.0	100.0	93.8	100.0
80	88.7	83.3	94.1	93.8	87.7	99.9
120	67.0	62.1	72.0	75.6	70.1	81.1
160	38.7	33.0	44.4	47.5	41.1	53.9
200	8.4	2.8	14.0	11.7	5.4	17.9
210	1.1	0.0	8.1	1.7	0.0	9.5

Table 4
Experimental results obtained from the evaluation of the infectivity of *M. incognita* juveniles

Trait	Control group mean ± standard deviation	Treatment group mean ± standard deviation	*p*-value for difference
Air dry weight (g)	7.163 ± 0.827	8.999 ± 0.846	5.043e-10
Dry weight of the root (g)	1.443 ± 0.177	1.757 ± 0.250	6.744e-06
Number of leaves	24.20 ± 2.35	24.44 ± 2.29	0.7161
Nodulation	3.68 ± 0.85	0.52 ± 0.51	2.816e-10

(p = 0.746) slope (–0.02874) is obtained, that is, the reactor components (peristaltic pump and static mixer with TiO_2) or the passage of the nematodes within the reactor, for 80 min, do not significantly affect motility. Conversely, the opposite results were obtained when the photoreactor was exposed to solar radiation because there were no motile nematodes 30 to 60 min after the trial began (Fig. 6 – differences between both replications could be attributed to different solar irradiance because the tests were run on different days). Overall, there are significant differences between both treatments, as seen in the confidence limits in Table 1, as early as at 30 min, and a 0% estimate for the percentage of motile juveniles at 60 min under the UV radiation treatment. This effect could be caused by the photocatalytic process of TiO_2, solar radiation or both. Therefore, the following test (3.2) involved the comparison of the effect of a reactor with TiO_2 with that of a reactor without TiO_2.

When the percentage of motile juveniles is plotted as a function of time spent at the reactor, there are variations in the response at the same time for the different replications that can be the result of differences in solar irradiance, that is not constant over replications. Using Q_{UV} instead of time corrects the variations in irradiance and permits better comparison between experiments and with results presented by other researchers [23]. Therefore, the results of the remaining sections are reported as a function of Q_{UV}.

3.2. Motility test with M. incognita juveniles (a) without TiO_2 and (b) with TiO_2

The results of this test are shown in Fig. 7, where it can be seen that both curves follow the same pattern and both reach zero at an accumulated Q_{UV} between 57 (replication 4) and 87 (replication 2) kJ/L. There are significant differences between both treatments at 20 and 40 kJ/L in favor of the without TiO_2 treatment, but these differences disappear from around 60 kJ/L (Table 2) and, the percentage of motile juveniles reach zero around 72 kJ/L (Fig. 7). Wang and McSorley [24] reported that juveniles of *M. incognita* incubated at 38°C were not completely killed after 40 h of thermal treatment in the absence of solar radiation. As the temperature during testing never exceeded the 30°C during the 50 min test, the loss of motility can only be attributed to the effect of radiation.

3.3. Egg hatching test of M. incognita with TiO_2 and without TiO_2

The curves obtained in the reactor with TiO_2 and the one without it are illustrated in Fig. 8. Similar results are observed in the juveniles (Fig. 7) because both curves follow the same trend –albeit a different shape- as incoming energy accumulates. In this case, no significant differences are found between the two treatments due to TiO_2 activity since the intervals in Table 3 are always overlapping. Notably, in this case, the nematode eggs are completely inactivated, that is, they no longer hatched at around 215 kJ/L of UV radiation (Fig. 8), unlike the juvenile nematodes, which lost motility using one-third of this energy. This is not surprising because the nematode egg-shell is one of the most resistant biological structures and can be regarded as a structure developed to increase the survival of the enclosed organism [25]. Considering that complete suppression of *M. incognita* egg hatch due exclusively to temperature without

radiation has been reported to require 389.8 h at 38°C [23] and that temperature during treatment never exceeded 30°C, the observed effect could be attributed exclusively to solar radiation.

3.4. Infectivity test of M. incognita using lettuce in a hydroponic system

Regarding the evaluation of the infectivity of *M. incognita* juveniles on the roots of hydroponic lettuce in NFT module systems, the results of an experiment involving 25 plants irrigated with treated water and 25 plants irrigated with untreated water (control) are shown in Table 4 and Fig. 9.

Experimental results show that the mean air-dry weight of the treatment group is greater than that of the control group ($p = 0.0000$) with an estimated 25% extra weight. The fact that the number of leaves in each group is not significantly different ($p = 0.7161$) points to a difference in biomass yield; the same effect can be seen with the dry weight of the root with an estimated 22% extra yield. These results are related to the number of nodules; in the untreated group the nodulation has a value of 3.68, greater than the value of the treated one of 0.52 ($p = 0.0000$); the nodulation caused by nematode infection disrupts many physiological processes which produce decreased biomass and yield [26].

Our results support the use of solar disinfection as a tool to diminish nematode infections as having been suggested previously [8] and, more importantly, the control of nematodes in reclaimed water whose purpose is the irrigation of crops [6].

4. Conclusions

This research shows that solar disinfection is a promising method to treat nematode infested water. The experimental results show that the motility of *M. incognita* nematode juveniles diminishes below 50% after 40 kJ/L of accumulated Q_{UV} and reach a 0% around 72 kJ/L. For the inactivation of *M. incognita* hatching, it was observed value over 50% with 160 kJ/L and almost full inactivation with 215 kJ/L. In both cases, the disinfection was done controlling the temperature below 30°C to avoid the thermal inactivation. The solar treatment of water-bearing nematodes reduces their infectivity as shown by lettuce hydroponics, which has been demonstrated by observing a decrease in root nodulation and an increase in the dry weight of the root and the leaves, compared to that in lettuce irrigated with untreated water. However, we have not found significant differences in treating nematode-infested water using the reactor with TiO_2 or without said photocatalyst, since experimental results suggest that the disinfection effect is mainly due to UV radiation. The proposed solar disinfection method can be used as a chemical-free alternative to prevent the nematode infection caused using recycled waters; then we suggest treating recovered water using the proposed solar disinfection method to verify the feasibility of this method with water-bearing other components.

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