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Tomato Crop Health, Yield, and Greenhouse Soil Conditions after 17 Years of Repeated Treatments of Biofumigation and Solarization

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ABSTRACT

The combination of biofumigation and solarization is known as bio-solarization. An experiment was performed from 2003 to 2019 in a greenhouse at INTA San Pedro, Buenos Aires province, Argentina (33°44'12.7"S 59°47'58.2"W). Treatments (TRAT) were applied every two years. TRAT evaluated were: 1=Control; 2= Solarization, 3= Biorot, a succession of organic amendments (chicken manure, broccoli, chicken manure, broccoli, tomato, and pepper crop debris, mustard, tomato crop debris, broccoli, tomato crop debris), 4=Biobras based only on the use of brassicas (rapeseed, broccoli, mustard, and *Brassica campestris*). Treatments were carried out in spring or summer so that a late-season tomato crop could be grown after them. The tomato hybrid planted was Superman (Petoseed), except for the last season where the hybrid used was Rodeo (BHN). Fungal pathogens controlled were *Pyrenochaeta lycopersici, Fusarium solani, Sclerotium rolfsii*, and *Sclerotinia sclerotiorum*, and nematodes like *Nacobbus aberrans*, *Helicotylenchus* and *Criconemella*. Fungi of Aspergillus genera were observed growing on death sclerotia of *Sclerotinia sclerotiorum* and *Sclerotium rolfsii* in Biobras and Biorot. Tomato plants in control showed a higher percentage of dead plants, root rots, and lower root dry matter at the end of each crop. Solarization alone without adding organic matter reduced this parameter in the soil and showed more death plants and less yield than Biobras and Biorot. Tomato and pepper crop debris used as biofumigants produced high yield values and adequate pathogen control. Biofumigation in combination with solarization is an effective technique for managing soil-borne pathogens in greenhouses and is being adopted by horticultural growers in Argentina.

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1. Introduction

Biofumigation has proved to be efficient for nematode and soil-borne pathogens control in many countries [1-10]. In Argentina, horticultural crops are produced along a wide territory under very different climatic conditions. Biofumigation has been assayed mostly under protected cultivation where intensive use of soil originates high populations of nematodes and soil-borne pathogens. Positive experiences have been held in Jujuy, Salta, Corrientes, Entre Ríos, Tucumán, Mendoza, Córdoba, Río Negro, Neuquén, La Pampa, etc. [11]. The combination of biofumigation and solarization [12] is known as bio-solarization (Biosol), it combines the exothermic reaction that occurs in the fermentation of non-composted organic matter incorporated into the soil, with the thermal and gas sealing action due to the glass plastic used [13] and is being adopted in many countries for soil disinfection [14-17].

Solarization (SOL) allows the survival of some groups of microorganisms [17]. In general, plant parasitic microorganisms are killed by temperatures lower than those needed to control saprophytic organisms, including many antagonists, which are more thermotolerant than pathogens [17-19]. This technique has a positive effect on plants growth and yield but could negatively affect soil properties [20-21]. Farmers have adopted SOL in the northeast and northwest regions of Argentina, where hot conditions in summer (mainly during January) make it impossible to cultivate in the greenhouse [11]. These farmers add manure to the soil prior to solarisation, so they performe bio-solarization (solarisation + biofumigation) treatment in most cases.

Satisfactory results In Argentina have been obtained by applying bio-solarization adding chicken manure to the soil with the objective of controlling *Ralstonia solanacearum*, *Pythium aphanidermatum, Rhizoctonia solani*, and *Sclerotium rolfsii* [22-24]; chicken manure in combination with broccoli [21]; chicken manure, sorghum, or Brassicas against weeds and damping-off pathogens [25-26]; rapeseed against *Phytophthora*, *Pythium*, *Verticillium*, *Macrophomina*, Rhizoctonia and nematodes as *Meloidogyne* and *Ditylenchus* [27]; cattle manure with cauliflower debris, and *Melia azedarach* seeds against *Meloidogyne hapla* [28-29]. In regions of wild winter where greenhouses are used all year-round, growers have difficulties applying bio-solarization in summer, so spring periods should be assayed for this technique application. Short periods with moderate temperatures in addition to broccoli residues have been demonstrated to reduce populations of *Meloydogine incognita* [30].

In order to study the effect of repeated application of bio-solarization on soil quality, pathogenic and beneficial microorganisms populations, a long-term experiment was carried out at INTA San Pedro, Province of Buenos Aires, Argentina (33° 41'S;59°41'W).

2. Materials and Methods

2.1. Experiment Design

The experience was carried out since 2003 in a macro-tunnel greenhouse (8x50 m), dedicated to horticultural production since the nineties, where the presence of the nematode *Nacobbus aberrans* had been detected in 2000 (Figure **1**). The climate of the area is temperate, with a moderate winter. The soil where the experiment was carried out is a Vertic Argiudoll with a B horizon enriched in clays. Water used for irrigation has pH 7.8, and it has high values of sodium bicarbonates. Plots (16 m²) were isolated from each other by means of 40 cm deep trenches coated with 200-micron black polyethylene. Prior to the experiment, 7 kg of soil containing roots of tomato plants infested with the nematode *Nacobbus aberrans* was added to each plot. Treatments (TRAT) were carried out every two years in spring or summer so that a late-season tomato crop could be grown after them. TRAT evaluated were: 1=Control; 2= Solarization, 3= Biorot, bio-solarization based on a succession of different organic amendments, 4=Biobras bio-solarization based on the use of brassicas. The materials used in Biorot were: chicken manure, broccoli, chicken manure, broccoli, tomato, and pepper crop debris, mustard, tomato crop debris, broccoli, tomato crop debris. The sequence applied in Biobras was: rapeseed, broccoli, mustard, and *Brassica campestris*. Tomato hybrid Superman (Petoseed) was planted until 2016, except for the last season where the hybrid used was Rodeo (BHN). Soil treatments were repeated in four randomized complete blocks.

Figure 1: Macro-tunnel where the experiment has been carried out since 2003.

2.2. Application of Organic Amendments

Treatments began in spring 2003 (Table **1**). Oilseed rape cultivar Mistral was grown in another greenhouse. The stems were cut into 20 cm pieces when the plants were in full bloom; they were weighed and distributed in the

Table 1: Treatment duration, kg/m² and composition of biofumigants applied.

	Chicken Manure	Rapeseed	Broccoli	Chicken Manure	Broccoli	Broccoli
	2003		2005	2007		2009
Days	35		31	42		41
Season	Late spring 14 nov/19 dec		Late spring 25 nov/26 dec	Summer 18 dec/ 29 jan		Late spring 18 nov/29 dec
Fresh matter Kg/m²	2.76	4.9	14.39	4.00	4.00	7.80

	Tomato and pepper debris	Mustard	Mustard	Tomato debris + P. oleracea	B. campestris	Broccoli	B. campestris	Tomato debris
	2011		2014	2016		2017	2019	
Days	32		12	27		36	37	
Season	Early Summer 2 dec / 3 Jan		Summer 22 Jan / 10 Feb	Summer 19 Jan / 15 Feb		Summer 21 dec / 25 Jan	Early Summer 11 dec / 17 Jan	
Fresh matter Kg/m²	1.20	1.35	1.30	1.50 + 6.08	0.36	19	7.5	9.76

greenhouse where the trial was conducted (Figure **2**). In 2005 and 2009, broccoli residue obtained in the same greenhouse was applied. In 2007 chicken manure (Biorot) and broccoli crop residue (Biobras) from another greenhouse were applied. In 2011 a mixture of composted residue from tomato and bell pepper crops grown in the greenhouse was applied in Biorot, and in Biobras, a mustard crop residue grown outside the greenhouse. The residue contained stems (77%), siliques (22%), and seeds (1%), but no roots. This biofumigant was also used in 2014. In 2016, Biorot treatment was based on tomato residue together with purslane (*Portulaca oleracea*) from the same plots, while in Biobras wild turnips (*Brassica campestris* L.) were in full bloom, collected at open-field in the experimental station was applied. In 2017 the biofumigant consisted of broccoli stems and leaves of a crop grown in the same plots (Figures **3-5**). In 2018 composted tomato debris (Figure **6**) was applied in Biorot, while in Biobras wild turnips (Figure **7**) were in full bloom. Solarization consisted of covering the plot with plastic without adding organic matter; the control treatment never received any organic amendment, nor was it covered with plastic. Air and soil temperature records were taken during the treatments using automatic sensors. The biofumigants were incorporated into the soil using a rototiller, then drip irrigation hoses were placed, and plots were covered with 50 microns polyethylene glass, except for the last year in which a five years old polyethylene of 150 microns that has been previously covering the greenhouse was used. No synthetic fertilizers were used during the process.

2.3. Soil Parameters Evaluated

Before and after treatments, the soil was sampled for chemical and physical-chemical analysis. Samples were taken in the superficial horizon (0-12 cm), parameters measured were potentiometric pH, soil extractant ratio 1:2.5, electrical conductivity in the extract, organic carbon (Walkley and Black), total nitrogen (via Semi-Micro-Kjeldahl method), and phosphorus via modified Bray 1 method (INTA, 1989). The content of cations, calcium, magnesium, potassium, sodium, and the percentage of exchangeable sodium was evaluated [31].

Figure 2: Oilseed rape cultivar Mistral grown in another greenhouse.

Figure 3: Broccoli grown in bio-solarized plots.

Figure 4: Chipping broccoli residues.

Figure 5: Chipped broccoli residues prior to its distribution.

Figure 6: Tomato residues were solarized after being removed from the greenhouse and composted for two years.

Figure 7: Wild turnip collected near the INTA Experimental Station.

2.4. Study of Nematode and Soil Pathogen Populations

In the center of each main plot, gauze bags containing 1 kg of soil were placed at 10 and 35 cm depth before the treatments (Figure **8**). Gauze bags containing 100 g of sterile soil with conidia of *Pyrenochaeta lycopersici* and *Fusarium solani* (concentration 9.63 x 10^5 and 3.45 x 10^4, respectively) and sclerotia of *Sclerotinia sclerotiorum* and *Sclerotium rolfsii* (6 and 40, respectively) (Figure **9**). After the treatments, 100 g was taken from each sample and sent to the Nematology laboratory of INTA Balcarce. The sclerotia were sown on 2% potato dextrose agar (PDA), and a 10^{-4} dilution was prepared with the soil samples and sown on the same culture media with and without antibiotics. A 10^{-3} soil dilution was sown for *Fusarium solani* and 10^{-5} for *Pyrenochaeta lycopersici*. Nematodes were separated from a 100 cm^3 aliquot of soil from each sample after homogenization, using the centrifugation technique [32]. Three tomato seedlings (Superman hybrid) per sample were used as indicator plants; these were transplanted when they had three true leaves into 1 L pots containing a mixture of one part of problem soil and two parts of a sterile substrate. Forty-five days after transplanting, the number of galls per g of root dry weight was analyzed.

Figure 8: Soil samples introduced prior to treatments application.

Figure 9: Sclerotia of *S. sclerotiorum* and *S. rolfsii* conditioned to be introduced in the soil.

2.5. Parameters Evaluated on the Crop

Tomato hybrid Superman was planted in double furrows at 50 cm from each other and a distance between plants of 40 cm. Total and commercial yield in kg/m^2, number of galls/g root dry matter (GAL), dead plants after transplanting, dead plants (DPL), and percentage of root rots (RROT) at the end of the cycle were evaluated.

2.6. Statistical Analysis

The data obtained were subjected to analysis of variance. The GLM procedure of the SAS statistical program and University SAS was used for this purpose. The arcsine transformation was performed on the percentages and square root on the variables that were the product of counting.

3. Results

3.1. Temperatures Recorded During Treatments

Soil temperatures registered during the spring treatments were at a lower limit than those usually recorded during solarization (Figure **10**). In summer, higher temperatures were obtained and adequate for soil pathogens control (Figure **11**). Soil temperatures showed a thermal amplitude varying between 25 and 40 ^{o}C; daily oscillation at 35 cm depth was lower than at 10 cm. In 2005 and 2009, higher temperature values were observed at 35 cm depth than at 10 cm. In these years, there were no differences between the untreated control and solarization; even in 2009, temperatures were higher, i.e., at 35 cm in control.

3.2. Effect of Treatments on Soil Chemical Parameters

Soil showed changes in its chemical parameters from the beginning of the trial, in part due to the composition of the water used to irrigate the crops that is rich in sodium bicarbonate. Prior to the last treatment, the greenhouse was left without its cover for one month to allow some beneficial rainfall effects. An increase in soil pH was observed in all plots, with modifications due to the application of treatments. In 2005 and 2009, pH

showed lower values in bio-solarized plots after treatments; in both cases biofumigant used was broccoli (Figure **12**). EC showed higher values after treatments (Figure **13**); in 2007 and 2009, bio-solarized soil increased its electrical conductivity but presented lower pH, higher percentages of total nitrogen, higher percentages of assimilable phosphorus, calcium, magnesium, and potassium. The plots that received chicken manure showed the highest assimilable phosphorus values. Solarization increased the percentage of exchangeable sodium in January 2007.

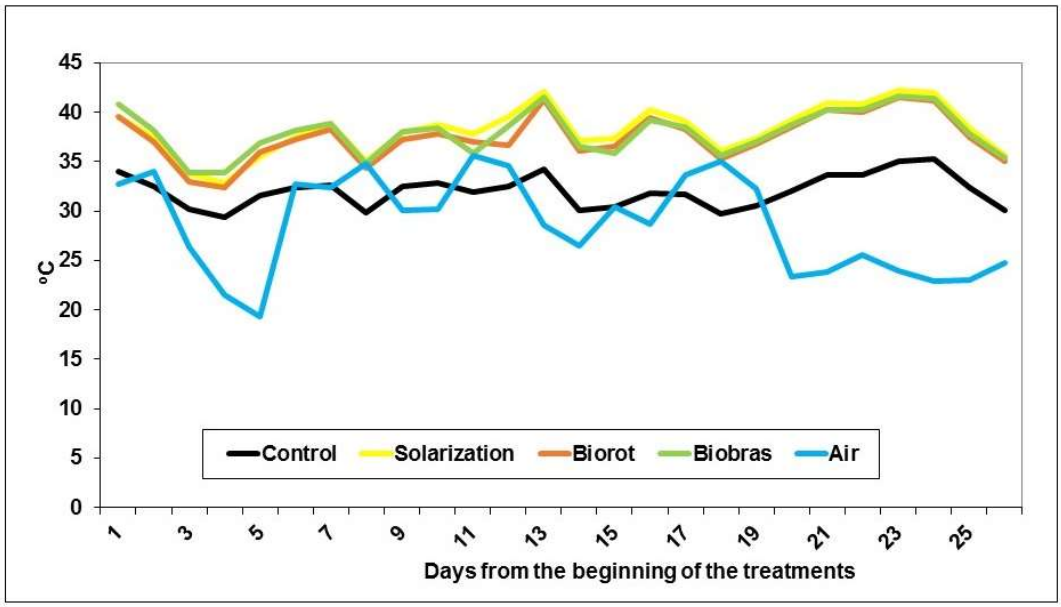


Figure 10: Soil and air temperatures recorded in the greenhouse during spring treatments carried out from November 14 to December 19, 2003.

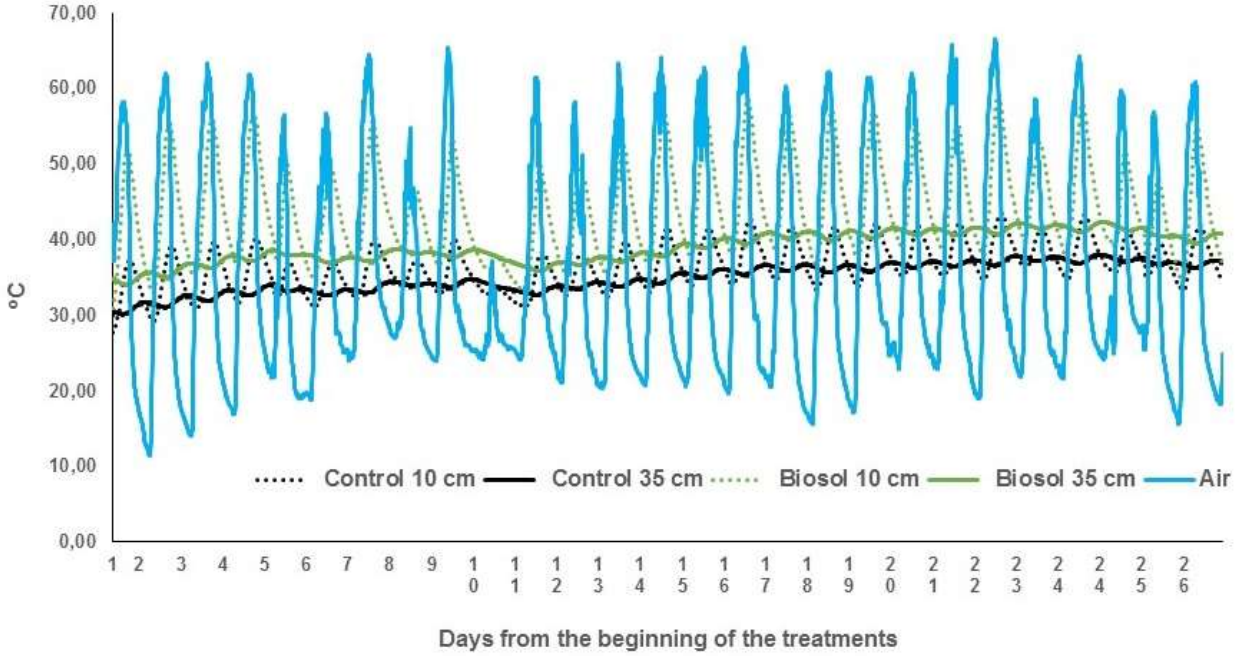


Figure 11: Soil and air temperatures were recorded in the greenhouse during summer treatments carried out from December 11 to January 17.

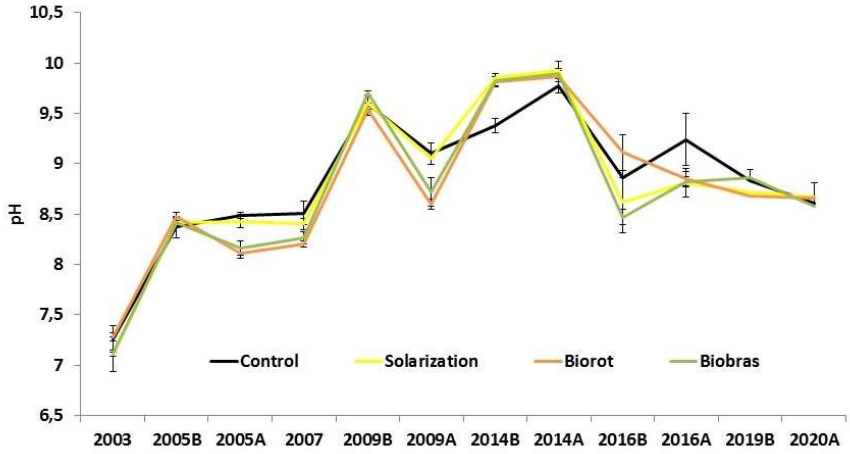


Figure 12: Evolution of soil pH before (B) and after (A) bio-solarization treatments.

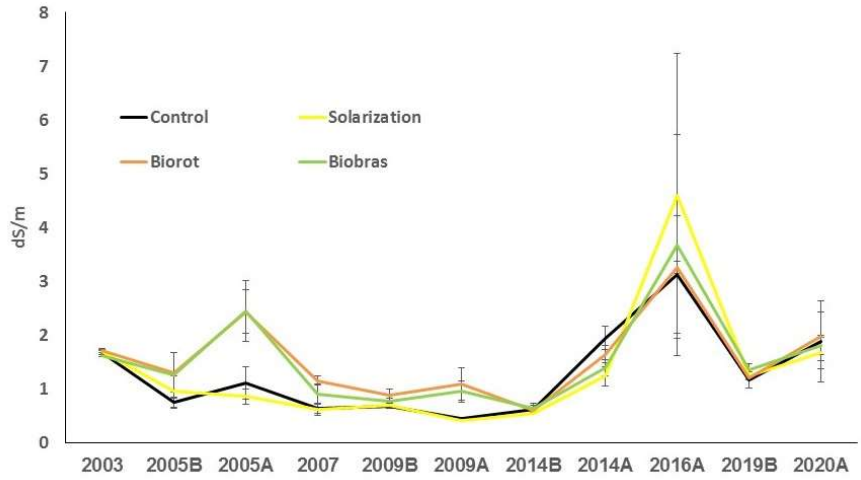


Figure 13: Evolution of soil electrical conductivity (EC) before (B) and after (A) bio-solarization treatments.

In 2014, soil analyses before and after treatments only showed highly significant differences ($p < 0.01$) between treatments for % Ca and Magnesium, with the highest values for Biorot. Analyses after treatments showed significant differences for EC and % exchangeable Na and highly significant differences for % OM, assimilable phosphorus, and % exchangeable K. Control plot and Biorot showed the highest EC values, solarization showed the lowest organic matter values, and Biorot showed the highest phosphorus values. The most important effect is the drop in OM after treatments, especially in solarized plots as a consequence of its mineralization in the successive treatments, and the attenuating effect observed in the Biorot treatment (Figure **14**).

3.3. Changes in Nematode Population

From the beginning of the trial, a reduction in the presence of gall-forming nematodes was observed in tomato crops evaluated, especially in the first ten centimeters of soil. This reduction was also observed in the untreated control without plastic cover, perhaps due to the high temperatures registered in the closed greenhouse and the lack of a susceptible host during the process. Bioassays using tomato plants allowed to detect statistically significant differences between treatments for GAL. No consistent differences were observed between solarization and bio-solarization. The sum of all phytophagous nematodes (*Nacobbus aberrans*, *Helicotylenchus spp*. and *Criconemella spp*.) showed differences before treatments in 2005 and after treatments in 2005, 2007, and 2009 (Figure **15**). In analyses conducted more than 24 months after biofumigation, significant differences ($p<0.05$) were detected in the population of *Nacobbus aberrans*.

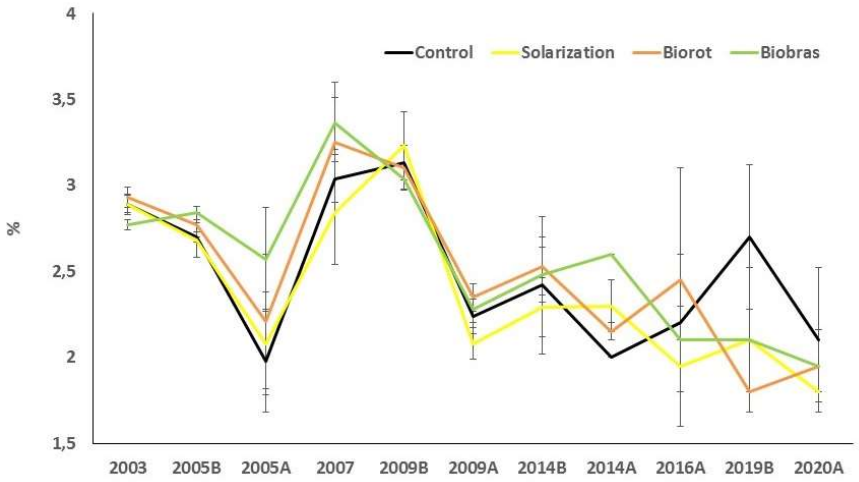


Figure 14: Evolution of organic matter (OM) before (B) and after (A) bio-solarization treatments.

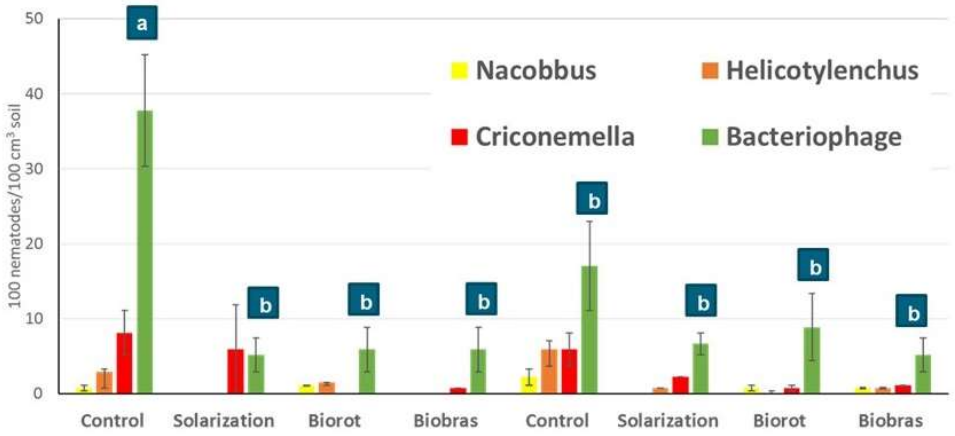


Figure 15: Nematodes/100 cm^3 of soil after treatments. December 2005. Biorot = Manure/Broccoli, Biobras = Rapeseed/ Broccoli. Media with different letters statistically differ for the Duncan test at 5 %.

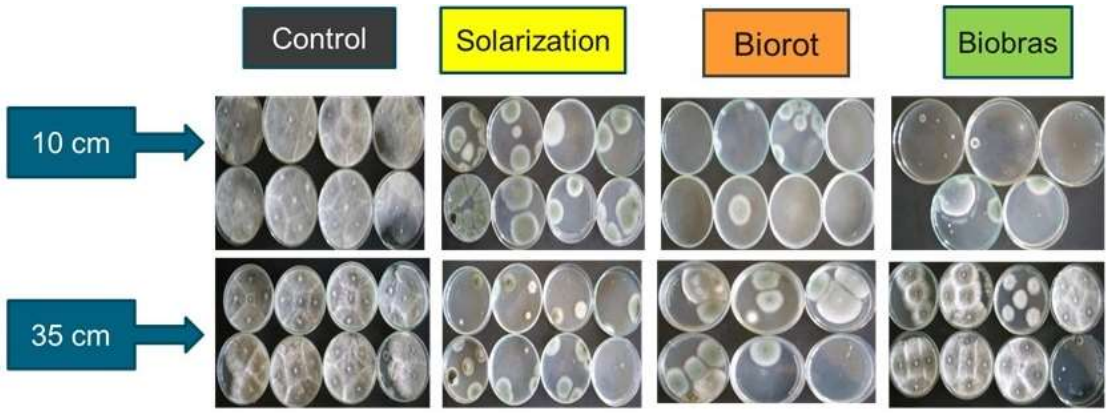
3.4. Effect of Treatments on the Survival *Sclerotium rolfsii*

In 2005, treatment depth interaction was highly significant ($p<0.01$) for the percentage of *Sclerotium rolfsii*, *Fusarium spp*., *Aspergillus spp*., and *Penicillium spp*. colonies recovered from *S. rolfsii* sclerotia after solarization and bio-solarization. The percentage of *Sclerotium rolfsii* colonies recovered was higher in the control, but at 35 cm, the effect of the treatments was lower; these results are similar to that obtained in 2014. In 2005, colonies of *Fusarium spp*. were recovered only at 35 cm, except in the solarization treatment. *Trichoderma spp*. was present in the control and in the treatments at 35 cm, with the exception of Biobras. Similar results were observed in 2014 with the appearance of some *Fusarium* colonies in the control. In 2016, pathogen control was total in the solarization and bio-solarization treatments. The predominant genus growing on sclerotia was *Aspergillus spp* (Figure **16**).

3.5. Effect of Treatments on *Sclerotinia sclerotiorum*

In 2005, although the differences were not statistically significant, the number of sclerotia of *Sclerotinia sclerotiorum* recovered after the treatments were higher in the control; colonies of *Fusarium spp*. were observed on the sclerotia in the control and in all treatments at 35 cm depth. In solarization and bio-solarization samples, colonies of *Aspergillus spp*. were observed at 10 cm depth. In 2014 differences between treatments were significant ($p<0.05$), maintaining a similar trend for *Fusarium spp*. colonies and a high percentage of *Aspergillus spp*. colonies growing on sclerotia at 10 and 35 cm. In 2016 *Sclerotinia sclerotiorum* control was total in the solarization

and bio-solarization treatments, and the predominant genus growing on sclerotia was *Aspergillus spp* (Figure **17**). A higher level of colonization was observed in the control, with respect to the solarization, Biorot, and Biobras treatments, with averages of 1=84.50±5.07 A, 2=66.53±8.52 AB, 3=49.67±9.25 B, and 4=49.70±8.21 B. In all cases, the genus growing on the sclerotia was *Aspergillus spp*.



Biobras = bio-solarization with broccoli debris, Biorot = bio-solarization with chicken manure

Figure 16: Germination of *Sclerotium rolfsii* after treatments in 2007. Fungus of Aspergillus genera growing on death sclerotia in Biobras and Biorot.

Figure 17: Germination of *Sclerotinia sclerotiorum* after treatments in 2016.

3.6. Effect of Treatments on the Population of *Fusarium solani* and *Pyrenochaeta lycopersici*

CFU of *Fusarium solani* in 2005 showed significant differences ($p<0.05$) for the interaction treatment*depth; this pathogen was found only in control at 10 cm but in all treatments at 35 cm. In 2014 highly significant differences ($p<0.01$) were obtained for the interaction treatment depth, with a lower presence of the pathogen in the treated plots and at 35 cm. *Pyrenochaeta lycopersici* colonies could not be recovered after the treatments, and in 2009 a reduction in the population of *Pythium spp.* was observed.

3.7. Effect of the Treatments on Plants Survival, Root Rots, and Galls/g Root Dry Matter

From the beginning of this experiment, the percentage of dead plants at the end of the crop cycle was always higher in the control (Figures **18-19**). From 2006 onwards, solarization differed from bio-solarization, possibly due to less favorable edaphic conditions for the host as a result of repeated SOL treatments without organic matter

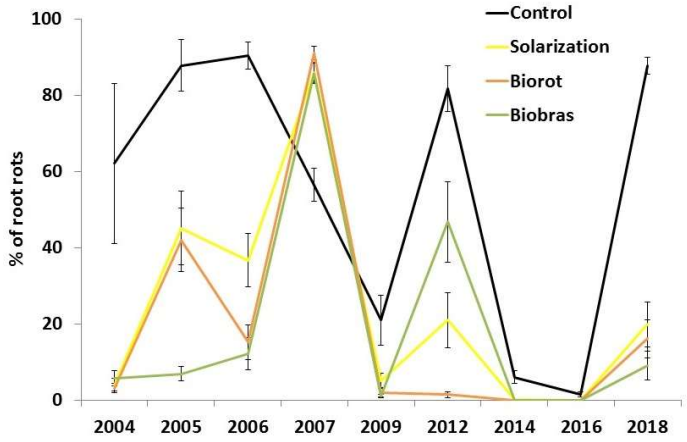


Figure 18: Percentage of dead plants at the end of the crop cycle.

Figure 19: Dead plants in control and bio-solarized crops.

inputs. In 2005 highly significant differences ($p<0.01$) were obtained for dead plants at the end of the cycle, galls per g of a root, and percentage of root rots. The pathogens isolated from the roots were *Pyrenochaeta lycopersici* and *Fusarium solani*. *P. lycopersici* was more frequently present in the control. GAL was higher in the plots where there was a higher percentage of healthy roots, possibly due to the fact that the rest of the galls were lost before they could be evaluated. In 2014, highly significant differences were obtained between treatments ($p<0.01$) for GAL and RROT, with the highest values for the control, the presence of galls was very low in all cases.

A higher number of galls per gram of root dry matter was observed in the control during all the experiments, but no clear differences were observed among the rest of the treatments (Figures **19-20**). In 2016 no GAL was observed in the samples taken at 45 of the treatments, whereas at 90 days, the means were: 1=2.9±1.72, 2=0, 3=0.9±0.9, 4=0.±0.03. At the end of the tomato crop cycle in 2016, only galls and root rots were observed in the control with very low levels. In 2018, the same effect was observed for galls, and the difference between the percentage of root rots was highly significant ($p<0.01$).

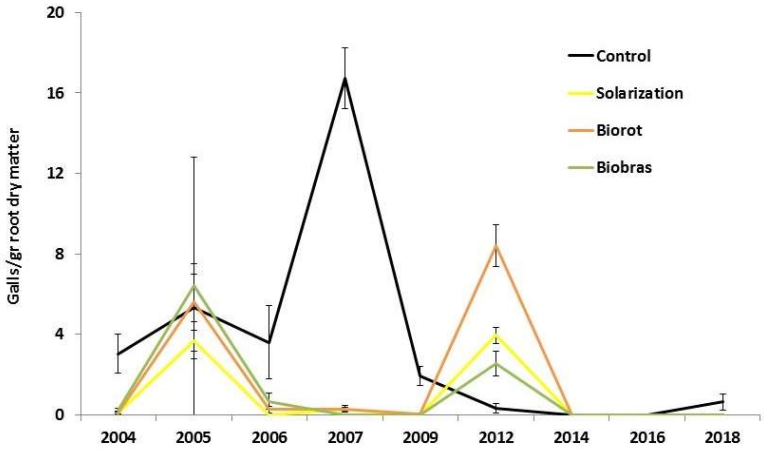


Figure 20: Galls per gram of root dry matter at the end of each tomato crop cycle.

3.8. Weed Control and Effect of Treatments on Tomato Crop Yield in kg/m^2

Weed control was satisfactory for all treatments except for control (Figure **21**), which also showed lower yields in all years of the experiment. Since 2007 solarized plots began to differ significantly from the bio-solarized ones

Figure 21: Weed presence in control (left) and in bio-solarized and solarized plots (right).

for crop yield; this effect could be due to less favorable edaphic conditions for the host as a result of repeated solarization treatments without organic matter inputs (Figure **22**, Table **2**). Higher yields were obtained after the application of tomato and pepper residue as biofumigant in 2011.

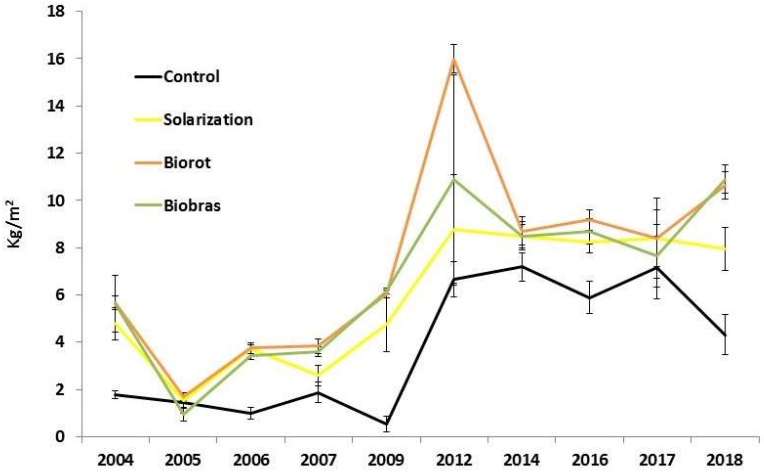


Figure 22: Effect of treatments on tomato yield in kg/m^2.

Table 2: ANOVA for yield (kg/m^2) tomato cv Superman and Rodeo (last year only) in 2003, 2005, 2007, 2009, 2012, 2014, 2016, 2017 and 2018.

Source	2003	2005	2007	2009	2012	2014	2016	2017	2018
TRAT	15.49 *	39.49 **	6.95 *	16.12 **	3.10 *	11.67 **	4.91 *	2.31 ns	11.72 **
Rep	6.15 ns	0.02 ns	1.45 ns	0.43 ns	1.10 ns	8.30 **	10.58 **	27.70 ns	18.27 **
R square	0.95	0.92	0.74	0.85	9.74	0.68	0.76	0.61	0.83
Variance Coeficient	14.74	14.13	23.27	30.07	20.7	12.24	24.07	27.54	23.19
General Media	4.46	2.99	2.97	4.37	5.88	8.83	6.22	8.00	8.45

** statistical significant p ≤ 0,01; * statistical significant ≤ 0,05; ns = no statistical differences.

4. Discussion

4.1. Temperatures Recorded During Treatments

Soil temperatures registered during the spring treatments were at the lower limit of those usually recorded during solarization (35 - 60 °C), but similar to those informed as efficient for nematode control in trials where the addition of Brassicaceae tissues was combined with high temperatures. In these studies, the galling index caused by *Meloydogine incognita* was reduced to 0 by applying temperatures of 30 °C for 15 days [30]. Summer temperatures and daily oscillation observed were similar to those previously obtained in greenhouses in San Pedro [17-19]. These authors also reported the high-temperature values in control plots without plastic cover because when the greenhouse was closed, it accumulated heat during the solarization process.

4.2. Effect of Treatments on Soil Chemical Parameters

Soil plots showed changes in their chemical parameters from the beginning of the trial. The most important effect is the drop in OM in solarized plots as a consequence of its mineralization in the successive treatments and the attenuating effect observed in the Biorot treatment. These results are similar to those observed previously in San Pedro and Zárate, where a decrease in organic matter, an increase in total nitrogen, and current fertility were observed after solarization, to the detriment of potential soil fertility [20-21].

4.3. Changes in Nematode Population, *S. sclerotiorum*, *S. rolfsii, Fusarium solani*, and *Pyrenochaeta lycopersici* Control

From the beginning of the trial, a reduction in the presence of gall-forming nematodes was observed in tomato crops evaluated, especially in the first ten centimeters of soil. This reduction was also observed in the untreated control without plastic cover, perhaps due to the high temperatures registered in the closed greenhouse and the lack of a susceptible host during the process. Treatment depth interaction was observed for the survival of sclerotia and the presence of fungi growing on them. At 35 cm depth, more colonies of Thrichoderma, *Fusarium spp*., *Aspergillus spp*., and *Penicillium spp*. were recovered from *S. rolfsii* sclerotia. The results are similar to previous authors [17], who observed the presence of *Aspergillus* colonies growing on sclerotia of *Sclerotium rolfsii* subjected to solarization in January. *Fusarium solani* was found mostly at 35 cm depth after treatments; no *Pyrenochaeta lycopersici* colonies could be recovered after the treatments. This result could match with the fact that the pathogen attacks in low-temperature periods and that solarization is recommended for its control. The results obtained in this work are similar in part with others in which the incorporation of Brassicas significantly reduced the incidence of pathogenic fungi such as *Sclerotinia minor* in lettuce crops or *Verticillium dahliae* in tomatoes. However, it was not very effective in reducing the population of *Fusarium spp*. [1-10].

4.4. Effect of the Treatments on Plants Survival, Galls/Root Dry Matter, and Yield

From the beginning of this experiment, the percentage of dead plants at the end of the crop cycle was always higher in the control, where lower yields were obtained. From 2007 onwards, solarization differed from bio-solarization treatments for both parameters, possibly due to less favorable edaphic conditions for the host as a result of repeated solarization treatments without organic matter inputs. A higher number of galls per gram of root dry matter was observed in the control during all the experiments, but no clear differences were observed among the rest of the treatments. Good results have been obtained using tomato and pepper residues, in accordance with other authors [15].

5. Conclusions

The effect of the treatments on soil chemical and biological properties and pathogen population affected tomato plant health. The untreated control showed a higher number of dead plants at the end of each crop cycle. The effectiveness of bio-solarization treatments in spring to maintain greenhouse crop health in a region with a mild winter climate and without the use of chemically synthesized nematicides was demonstrated. It was also observed that solarization without the contribution of organic matter is not a sustainable practice since the percentage of organic matter was reduced. Bio-solarization increased the calcium, magnesium, and potassium content, elements favorable for crop growth and soil structure. Good results were obtained with composted tomato and bell pepper residues, which registered high yield values with an improvement in the production environmental performance.

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