

1 Article

2 Greenhouse soil biosolarization with tomato plant 3 debris as unique fertilizer for tomato crops

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11

12 **Abstract:** Intensive greenhouse horticulture can cause various environmental problems. Among
13 them, the management, storage and processing of crop residues can provoke aquifer
14 contamination, pest proliferation, bad odors or the abuse of phytosanitary treatments.
15 Biosolarization put in value any fresh plant residue and is an efficient technique for the control of
16 soil-borne diseases. This study aims to examine an alternative means of managing greenhouse crop
17 residues through biosolarization and to investigate the influence of organic matter on yield and
18 quality of tomato (*Solanum lycopersicum*, L.) fruit. With this purpose, the following nutritional
19 systems were evaluated: inorganic fertilization with and without brassica pellets (Fert, Fert + and
20 Fert ++), fresh tomato plant debris with and without brassica pellets (Rest, Rest + and Rest ++)
21 and no fertilizer application (Control). The addition of organic matter equaled all the treatments except
22 for control with regard to yield and quality of the tomato fruit. In light of these results, the
23 application of tomato plant debris to the soil through biosolarization is postulated as an alternative
24 for the management of crop residues, solving an environmental problem and having a favorable
25 impact on the production and quality of tomatoes as a commercial crop.

26 **Keywords:** tomato, biofumigation, organic, inorganic fertilizer, sustainability, environment.

27

28 1. Introduction

29 Protected agriculture in the Mediterranean basin has maintained a sustained growth over the
30 last decades due to the increase of human population and demand for vegetables. According to
31 Castilla [1], in 2010 the total area dedicated to the cultivation of greenhouse vegetables in the
32 Mediterranean basin was up to 200,000 ha. The province of Almería (south-east Spain), with a
33 protected area of 30,456 ha and commercial production of fruit and vegetables valued at 2,537 M €
34 (tomato production corresponds to 540 M€), was considered to be the main core of protected
35 horticultural production in Europe during 2016 [2].

36 However, the location of production has led to environmental problems, such as pollution and
37 eutrophication of aquifers, mainly due to the excessive use of pesticides, synthetic nitrogenous
38 fertilizers or excessive irrigation when chemical disinfection is applied [3-7]. Another problem is the
39 management of crop residues due to the seasonality in the waste production [8]. In particular,
40 Almería in 2014 produced approximately 1,900,000 tons of non-dehydrated residues from
41 horticultural crops [8, 9]. Furthermore, organic matter resources, such as green manure, mulching,
42 animal manure and crop waste, are frequently added to the soil through biofumigation and
43 biosolarization to prepare the soil for the next crop [10, 11].

44 Biosolarization [12], as a combination of biofumigation [13] and solarization [14], is a technique
45 which can involve the application of any type of organic amendment with disinfection properties to

46 the soil. The advantages of using the biosolarization technique include increased temperature due to
47 the combined action of plastic sheet and the decomposition of organic matter [15, 16], improved
48 water use and soil structure [17], reduced erosion and salinity [18], increased organic matter content
49 [19, 20], organic matter solubilization [21], CO₂ capture during the development of the biofumigant
50 crop [22] and acceleration of in situ decomposition of plant waste from crops which reduces the
51 transition time between crops [23].

52 Increased introduction of ecological systems of production (50.9 Mha worldwide) [24], and the
53 need for various organic amendments for plant nutrition, highlight greenhouse waste as viable for
54 application through biosolarization.

55 The aim of this study is to evaluate the addition of organic matter (i.e. crop residues) as
56 fertilizers and test if this organic amendment is sufficient to support profitable tomato crops grown
57 under an intensive production system.

58 2. Materials and Methods

59 2.1. Location, climate and soil

60 The trial was conducted in two consecutive years (2015-16, 2016-17) at the UAL-ANECOOP
61 Experimental Research Centre in Almería (36.518N, 2.178W). The local climate is Mediterranean arid
62 with mild winters and hot, dry summers (average annual rainfall below 250 L·m⁻²). The experimental
63 greenhouse was an Almería-type “raspa y amagado” greenhouse [25], the most common in the area.
64 The greenhouse was 1.700 m² in area, with a north-west to south-east orientation and crops rows
65 aligned north-east to south-west. The soil was composed of a mixture of sand and soil [26] and was
66 free of soil-borne pathogens. During the cropping periods, no soil treatments were applied. Soil
67 nutrition analysis was performed previously to plant transplant. Soil samples were taken in 7 points of
68 the greenhouse at a depth of 0–30 cm, the soil mix was analyzed by an accredited laboratory. At the
69 start of the experiment, the soil consisted of 14.33% clay, 72.24 % sand, and 13.43% silt. Soil pH was
70 7.56, organic matter content 0.78%, Total Nitrogen (N) 700 mg·kg⁻¹, available phosphorus (P) 61.43
71 mg·kg⁻¹, and exchangeable potassium (K) 365 mg·kg⁻¹.

72 The greenhouse had a drip irrigation system with 3 L·h⁻¹ emitters. In the same greenhouse
73 during previous years (2013-14 and 2014-15), two tomato crops were grown with the incorporation
74 of organic matter. In the first year, the crop was transplanted on September 2nd 2015 and remained
75 for 173 days. In the second year (2016), the crop was planted on September 6th and remained for 170
76 days. The plants were tomato cv. Pitenza F1 (Enza Zaden, NL) at a density of 2 plants·m⁻². Plants
77 consisted of a single stem; axillary shoots were eliminated and the plant was trained along a
78 polypropylene rope. Irrigation was performed based on readings of a Model R tensiometer
79 (Irrometer, Riverside CA) which was placed at a depth of 30 cm; irrigation was performed at
80 pressures between -15 and -20 KPa. Control of pests and diseases was carried out in a conventional
81 manner according to environmental practices and legislation. Pollination was forced with the use of
82 bumblebees at a density of 4 hives·ha⁻¹.

83 Air temperature in the greenhouse was measured using a Hobo U23 -001 Pro v2 temperature
84 data logger (Onset Computer Corp., Bourne, MA, USA). During the growing period, the minimum,
85 average and maximum temperatures in the greenhouse were 12.60 ± 2.14 °C, 18.13 ± 1.77 °C and
86 27.69 ± 3.06 °C in the first season, and 11.78 ± 4.16 °C, 18.52 ± 4.63 °C and 30.46 ± 6.05 °C in the second
87 season, respectively.

88 2.2. Experimental design, fertilization and soil disinfection

89 The experimental design comprised of seven treatments with four replications randomly
90 distributed in two large zones (i.e. organic and inorganic). In this way, three treatments were in the
91 inorganic zone and four in the organic zone of the greenhouse. Each elementary plot had an area of
92 40 m², each containing 80 plants. The two zones of the greenhouse each had an independent
93 irrigation system. In the inorganic zone of the greenhouse, the following treatments applied to the
94 soil with inorganic fertilization were used (the nutritive solution is reported in Table 1): Nutritive

95 solution (**Fert**); Nutritive solution and 0.5 kg·m⁻² of Biofence® (**Fert +**); Nutritive solution and 1
 96 kg·m⁻² of Biofence® (**Fert ++**). In the organic area of the green house, the treatments amended with
 97 different organic materials and/or exclusive irrigation with water without fertilizer were as follows:
 98 3.5 kg·m⁻² of fresh tomato plant debris (**Rest**); 3.5 kg·m⁻² of fresh tomato plant debris and 0.5 kg·m⁻² of
 99 Biofence® (**Rest +**); 3.5 kg·m⁻² of fresh tomato plant debris and 1 kg·m⁻² of Biofence® (**Rest ++**). The
 100 trial had a "zero" treatment (**Control**), which involved irrigation with water only, without use of
 101 fertilizer or organic matter. The nutritional characteristics of the commercial product, Biofence®, are
 102 presented in Table 1. For the preparation of the organic amendments, fresh tomato plant debris from
 103 the previous production cycle was chopped to a particle size of less than 3 cm using tractor-powered
 104 hammer grinders and incorporated into the soil with a rototiller at the previously reported doses.
 105 The tomato debris consisted of the remaining plants at the end of the previous crop. This material
 106 included neither fruits nor roots. The existing compositional data of tomato debris is sparse and
 107 shows considerable variability among various nutrient levels [27-30]. The chemical characteristics of
 108 tomato plant debris used were: Nitrogen (N) 4.12%, Phosphorus (P) 0.40%, Potassium (K) 2.83%,
 109 Calcium (Ca) 3.43% and Magnesium (Mg) 0.86%. The commercial product, Biofence®, was applied
 110 along the crop row prior to solarization of the specified treatments. All the treatments were
 111 subjected to biosolarization or solarization in the two growing periods for 60 days before
 112 transplanting the crop by covering the soil with a transparent polyethylene plastic sheet (0.05 mm
 113 thickness). The temperature was measured at 15-cm depth during the period of (bio)solarization at
 114 two points in the greenhouse using a Hobo U23-001 Pro v2 temperature probe (Onset Computer
 115 Corp., Bourne, MA, USA). Soil wetting was carried out after placing the plastic sheet using the same
 116 irrigation system, adding water at up to field capacity (30 L·m⁻²). Irrigation water was analyzed
 117 during the two years of research to confirm absence of fertilizer.

118 **Table 1:** Nutrition systems used

Nutritive solution	NO ₃ ⁻ : 11 mmol·L ⁻¹ , H ₂ PO ₄ ⁻ : 1.5 mmol·L ⁻¹ , SO ₄ ²⁻ : 2 mmol·L ⁻¹ , K ⁺ : 7.5 mmol·L ⁻¹ , Ca ²⁺ : 5 mmol·L ⁻¹ , Mg ²⁺ : 2 mmol·L ⁻¹ . C.E. increased from 0.5 to 3.0 ds·m ⁻¹ during crop development.
Biofence®	Dehydrated and defatted pellets of <i>Brassica carinata</i> , 6% N, 3.1% P, 2.2% K, 1.8% S, 0.5% Mg. Triumph Italia.

119 2.3. Parameters analyzed

120 2.3.1. Tomato yield

121 During the growth of the crop, several parameters were measured and/or calculated for each
 122 harvest, such as yield, accumulated yield (calculated) and weight per fruit, using a Metter Toledo
 123 electronic scale. The weight per fruit was obtained from the average weight of 25 fruits with
 124 representative characteristics of the sample set. Fruits were harvested which had suitable commercial
 125 characteristics and were of the desired ripeness for consumption.

126 2.3.2. Fruit quality

127 The quality of the tomato fruit was evaluated three times in each crop cycle, by using 10
 128 marketable fruits per experimental plot (280 fruits in each of the three samplings, 840 in total). The
 129 analyzed parameters were as follows: equatorial diameter with a digital caliber (Mitutoyo), firmness
 130 of the pulp with a penetrometer (Agrosta Penefel DFT14) with an end of 0.5 cm². Three
 131 measurements were taken in each fruit with gaps of 120. Prior to measurement, the fruit cuticle was
 132 removed at each site. Fruit pH was determined with a pHmeter Crison pH-25+ with penetrating
 133 electrode. Fruit soluble solids pulp content was measured with a digital refractometer (Atago pal-1)
 134 and color with a colorimeter (Konica Minolta CR400). Three measurements were taken in each fruit,
 135 in three equidistant places of the equatorial zone, with gaps of 120°. The tomato color values were
 136 recorded as a*/b*.

137 2.4. Statistical analyses

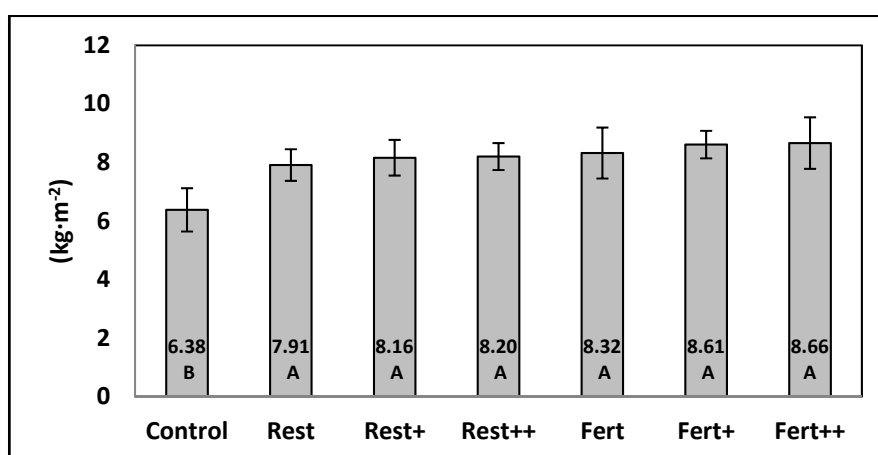
138 After finding that both trials could be considered statistically equal for the accumulated yield
 139 parameter, the results were analyzed as one individual experiment for a more consistent analysis.
 140 On the other hand, given that for the other tomato yield parameter (i.e. mean yield and weight per
 141 fruit) and for the quality fruit parameters the effect of year was significant and both trials could not
 142 be considered statistically equal, the results were analyzed separately. The analysis carried out for
 143 the comparisons between treatments consisted of simple analysis of variance (ANOVA) and means
 144 separated by Tukey's honest significant difference test ($P < 0.05$). As it is a parametric analysis, the
 145 conditions of normality and homoscedasticity were checked previously (Shapiro-Wilk and Levene
 146 tests, respectively). The statistical package used was STATGRAPHIC CENTURION XVI v16.2.04
 147 (Manugistic Incorporate, Rockville, MD) for Windows.

148 3. Results

149 3.1. Tomato yield

150 3.1.1. Accumulated tomato yield

151 The accumulated yield during both crops (Figure 1) was consistent and did not show
 152 differences depending on the nutrition system used. Treatments with crop debris (with and without
 153 Biofence®) produced the same yield as plants fertigated (with and without Biofence®). All the
 154 treatments produced higher yields than the control.



155 **Figure 1.** Effect of soil bio-disinfection treatments with tomato plant debris (with and without brassica pellets) as unique fertilizer, and inorganic fertilization treatments (with and without brassica pellets) in the accumulated yield of tomato fruits.

Organic supplements were applied 60 days before transplanting in two consecutive seasons (2015-16 and 2016-17). The results correspond to the average of two seasons.

Control = --; Rest = 3.5 kg·m⁻² tomato plant debris; Rest+ = 3.5 kg·m⁻² tomato plant debris + 0.5 kg·m⁻² Biofence®; Rest++ = 3.5 kg·m⁻² tomato plant debris + 1.0 kg·m⁻² Biofence®; Fert = Inorganic fertilization; Fert+ = Inorganic fertilization + 0.5 kg·m⁻² Biofence®; Fert++ = Inorganic fertilization + 1.0 kg·m⁻² Biofence®. Different letters indicate significant differences ($P \leq 0.05$, Tukey's HSD test).

156 3.1.2. Yield per harvest

157 The average yield for each harvest (Table 2) was similar with the first crop cycle (p -value >
 158 0.005); the control treatment produced substantially less throughout the cropping period, but yield
 159 was not significantly different from the others treatments. With the second crop, differences between
 160 treatments were observed, and as occurred in the accumulated production, the treatments with crop
 161 debris (with and without Biofence®) produced the same yield as the fertigated treatments (with and
 162 without Biofence®). With the control treatment, yield was lower with the second crop and was
 163 significantly different compared to the other treatments.

Table 2: Effect of soil biosolarization treatments with tomato plant debris (with and without brassica pellets) as unique fertilizer, and of inorganic fertilization treatments (with and without brassica pellets) on tomato yield and fruit quality variables in two growing seasons (autumn–winter).

Organic supplements were applied 60 days before transplanting in two consecutive seasons (2015-16 and 2016-17). The results correspond to the average of two seasons.

Treatment	Mean Yield (kg·m ⁻²)	Fruit Weight (g)	Size (mm)	Firmness (kg·cm ⁻²)	Soluble Solids (°Brix)	Fruit Acidity (pH)	Fruit Color (A*/B*)
Season 1. 2015-2016 (173 days)							
Control	0.70 ± 0.10	118.22 ± 10.06 C	61.28 ± 3.09 C	5.70 ± 0.76 A	5.31 ± 0.51 A	3.95 ± 0.12 C	0.69 ± 0.10 C
Rest	0.82 ± 0.11	123.34 ± 10.46 BC	63.02 ± 2.19 B	4.74 ± 0.68 B	5.27 ± 0.49 A	4.03 ± 0.16 B	0.73 ± 0.10 B
Rest+	0.83 ± 0.09	124.83 ± 9.97 BC	63.31 ± 2.58 B	4.45 ± 0.71 CD	5.01 ± 0.58 B	4.06 ± 0.14 AB	0.73 ± 0.10 AB
Rest++	0.83 ± 0.12	129.97 ± 7.01 AB	63.73 ± 2.44 B	4.45 ± 0.64 CD	5.17 ± 0.42 A	4.06 ± 0.16 AB	0.73 ± 0.11 AB
Fert	0.77 ± 0.08	127.35 ± 10.22 ABC	64.68 ± 2.50 A	4.43 ± 0.65 D	4.78 ± 0.58 C	4.09 ± 0.15 A	0.73 ± 0.08 B
Fert+	0.85 ± 0.08	136.16 ± 10.28 A	65.22 ± 2.17 A	4.69 ± 0.65 BC	4.65 ± 0.44 C	4.03 ± 0.15 B	0.75 ± 0.09 A
Fert++	0.83 ± 0.10	137.13 ± 3.93 A	65.38 ± 2.70 A	4.64 ± 0.59 BCD	4.67 ± 0.42 C	4.01 ± 0.16 B	0.74 ± 0.11 AB
p-value	0.6770	0.0016	0.0000	0.0000	0.0000	0.0000	0.0000
Season 2. 2016-2017 (170 days)							
Control	0.52 ± 0.07 C	106.45 ± 6.71 D	60.57 ± 3.28 D	5.65 ± 0.90 B	5.38 ± 0.55 B	4.12 ± 0.14 D	0.45 ± 0.11 D
Rest	0.70 ± 0.15 B	120.77 ± 12.25 C	63.97 ± 3.32 BC	5.70 ± 1.00 B	5.34 ± 0.59 B	4.13 ± 0.23 C	0.51 ± 0.11 C
Rest+	0.73 ± 0.13 AB	122.85 ± 11.24 BC	64.56 ± 3.26 B	5.56 ± 0.91 B	5.21 ± 0.60 BC	4.13 ± 0.11 C	0.51 ± 0.10 C
Rest++	0.74 ± 0.12 AB	126.32 ± 11.50 ABC	64.07 ± 3.06 BC	5.63 ± 0.96 B	5.27 ± 0.55 BC	4.11 ± 0.10 BC	0.52 ± 0.10 BC
Fert	0.81 ± 0.12 A	132.03 ± 5.68 A	65.64 ± 2.45 A	5.18 ± 0.89 C	5.10 ± 0.48 C	4.21 ± 0.27 AB	0.53 ± 0.11 AB
Fert+	0.79 ± 0.12 AB	127.01 ± 6.53 AB	64.81 ± 2.84 AB	5.59 ± 0.98 B	5.28 ± 0.49 B	4.16 ± 0.12 BC	0.52 ± 0.11 BC
Fert++	0.82 ± 0.13 A	124.63 ± 7.42 BC	63.60 ± 2.82 C	6.05 ± 0.96 A	5.63 ± 0.51 A	4.16 ± 0.23 A	0.55 ± 0.11 A
Control	0.52 ± 0.07 C	106.45 ± 6.71 D	60.57 ± 3.28 D	5.65 ± 0.90 B	5.38 ± 0.55 B	4.12 ± 0.14 D	0.45 ± 0.11 D
p-value	0.0000	0.0000	0.0000	0.0000	0.0000	0.0555	0.0000

Control = --; Rest = 3.5 kg·m⁻² tomato plant debris; Rest+ = 3.5 kg·m⁻² tomato plant debris + 0.5 kg·m⁻²Biofence®; Rest++ = 3.5 kg·m⁻² tomato plant debris + 1.0 kg·m⁻²Biofence®; Fert = Inorganic fertilization; Fert+ = Inorganic fertilization + 0.5 kg·m⁻²Biofence®; Fert++ = Inorganic fertilization + 1.0 kg·m⁻²Biofence®. *The same letter within columns indicates no significant difference (P<0.05, Tukey's HSD test).

164

165 3.1.3. Weight per fruit

166 The weight per fruit was affected during the first growing cycle by the type of fertilization
 167 (Table 2). The treatments with inorganic fertilization produced fruits of greater weight but was not
 168 significantly different from the others nutritional treatments except Rest and Control. Fruits from
 169 Rest + and Rest ++ treated soil were of similar weight to fruits with other treatments. In the second
 170 crop, treatments with crop residues produced fruits of similar weight as treatments with fertigation.
 171 During the two years, control fruits had lower weights compared to any other treatment in both
 172 years of cultivation.

173 3.2. Fruit quality

174 3.2.1. Size

175 The size of the tomato fruits was smaller in the treatments with crop residues in the first crop
176 (Table 2), although in the second crop treatments with crop residues produced fruits of similar size
177 to those from the treatments fertigated. In both years, control treatment was the one that produced
178 the smallest fruit. In all cases, the average size of the fruits was in the range of M values of 57 – 67
179 mm, which is a commercial standard.

180 3.2.2. Firmness

181 The firmness of the fruits (Table 2) was affected by the treatments in both production cycles. In
182 the first crop, the control fruits were the hardest compared to the other treatments. In the second
183 crop, there was no difference between most of the treatments, Fert ++, Rest and control being the
184 treatments with the highest firmness values. The Fert treatment produced the softest fruits.

185 3.2.3. Soluble solids

186 The fruits from soil treated with crop residues and the controls were the sweetest in the first
187 tomato crop. In the second crop, these differences were not apparent, with Fert ++ and Control
188 treatments resulting in the sweetest fruits; the other treatments resulted in fruits with a similar
189 soluble solids content (Table 2).

190 3.2.4. Acidity of the fruit

191 The fruit acidity (Table 2) was affected by the nutrition of the plants in the first crop. The control
192 fruits had a lower pH, and the rest of the treatments resulted in fruits with very similar values
193 although there was a significant difference between them. In the second crop, no significant
194 differences were observed between soil treatments (p -value > 0.005).

195 3.2.4. Color

196 The parameter A^*/B^* (Table 2) showed differences between treatments in the first crop,
197 although minimal and imperceptible to the human eye. The control treatment resulted in the lowest
198 values. In the second crop, the parameter A^*/B^* showed differences between treatments, which were
199 minimal and negligible, similar to the previous year because the harvesting took place at the same
200 point of maturity. Again, the control presented the lowest values during the second crop.

201 4. Discussion

202 Several authors have studied in depth the benefits for production of using techniques such as
203 biofumigation or biosolarization in several crops [31-42].

204 On the other hand, there are few studies in which plant nutrition based exclusively on the
205 addition of organic matter applied under biosolarization in greenhouse. Most authors supplement it
206 with synthetic fertilizer during the development of the crop. For this reason it is difficult to compare
207 the results with those from this study. The current results indicate that in both years the treatments
208 that received organic matter did not differ from those that were fertigated in parameters as punctual
209 and accumulated yield. Iapichino et al. [36] reported that tomatoes grown after carrying out the
210 biosolarization technique with brassica residue ($2 \text{ kg}\cdot\text{m}^{-2}$) and inorganic fertilization showed higher
211 commercial production than with only solarized treatments. Ros et al. [43] evaluated the
212 biosolarization technique with various organic materials (sheep and chicken manure) and reported
213 greater production of pepper fruit with the use of manures; the authors did not specify whether they
214 used an inorganic fertilizer in the culture.

215 Mauromicale et al. [44] reported an increase in tomato yield (up to 70% depending on
216 treatment) when organic matter composed of cow dung, poultry manure and leather was
217 incorporated into the soil prior to solarization. Again, Mauromicale et al. [16] found that the addition
218 of compost based on cattle or horse manure prior to solarization (i.e. biosolarization) had a positive
219 effect on the physical and chemical properties of tomato fruits in the south-east of Italy. Nuñez-Zofío
220 et al. [45], in a trial of biodisinfection of soils in the Basque Country, found improved production in
221 pepper crops after the addition of various organic materials, with an increase in production of 59%
222 with semi-composted sheep manure and poultry manure. The previous authors did not specify if
223 they performed inorganic fertilization during the development of the crop. Marín-Guirao et al. [11]

224 concluded that biosolarization with residues of brassicas and pellets of chicken manure
225 supplemented with inorganic fertilization benefited tomato crops, improving yield and organoleptic
226 tomato fruit characteristics. The findings reported by these authors demonstrate the positive effects
227 of biosolarization when it is supplemented with organic matter and fertigation, obtaining yields and
228 fruits with a fruit quality comparable to a conventional system. However, the application of
229 inorganic fertilization plus organic matter must be carried out taking into account the global
230 contribution of macronutrients to the system, in order to optimize resources and reduce costs. In this
231 sense, the current research is postulated as an evolution of the techniques used by the previous
232 authors, reducing the contribution of inorganic fertilizer to zero in the treatments with crop residues
233 and obtaining a comparable yield to that obtained with a conventional production system.

234 It is necessary to analyze the control yield; this treatment was solarized in both growing years
235 of this experiment. This could be the reason why commercial production levels were obtained,
236 although of a smaller amount due to the solubilization of remaining nutrients produced during
237 solarization. Stapleton et al. [21] found a similar effect when solarizing with transparent plastic; the
238 authors reported an increase in the content of NO_3^- and NH_4^+ available for post-solarization
239 cultivation. Lombardo et al., [39] quoting Katan [14], speculate that solarization by itself can
240 potentiate the growth and development of the plant by coining the term "increased growth
241 response" and suggest that this is due to a rapid release of nutrients.

242 The use of Biofence® as organic material did not provoke an improvement either in yield or in
243 the organoleptic properties of tomato fruit during both crops. Supplementation with the pellets
244 resulted in an improvement in yield, but not significantly. These findings are partly consistent with
245 those of López-Aranda et al. [46], Pane et al. [47] and Marín-Guirao et al. [11], who did not report
246 any benefit with Biofence® application. Pane et al. [47] suggest that the application of brassica
247 carinata flour, with or without solarization, could have a protective effect on some microbial groups
248 that benefit soil activity and establishment of the crop. However, Guerrero et al. [48] tested
249 Biofence® for the control of nematodes of the genus *Meloidogyne* did not demonstrate any benefits
250 from its use, as it was ineffective in controlling nematodes and had no positive effect on pepper
251 production compared to the use of fresh manures. With regard to this study, the use of the
252 commercial product, Biofence®, represented a financial investment with no corresponding increase
253 in yield to justify its use.

254 The quality parameters of the tomato fruit were affected by the type of fertilization. It should be
255 noted that the fruits from plants treated with fertigation, in the first year, had higher size and weight
256 than fruits of the others treatments, but not in the second year. Similar values to those values
257 reported by other authors: Marín-Guirao et al. [11] obtained values for acidity, °Brix and color
258 similar to this study. However, Mauromicale et al. [16] reported that parameters, such as firmness,
259 color and soluble solids content (°Brix), were increased proportionally to the increase in organic
260 matter in the treatments used, contrasting with the results of this study. In our study, the control
261 treatment showed an increase similar to was reported by Mauromicale et al. [16], which may be due
262 to the scarcity of nutrients with no organic amendment.

263 From a commercial point of view, the two systems of vegetable nutrition produced fruit
264 suitable for consumption: caliber M (57–67mm), very high firmness ($>2\text{kg}\cdot\text{cm}^{-2}$) and color between
265 the E-F categories. It should be noted that the values of °Brix and pH are closer to a "cherry" tomato
266 type than to a long-life tomato, [49, 50].

267 Authors should discuss the results and how they can be interpreted in perspective of previous
268 studies and of the working hypotheses. The findings and their implications should be discussed in
269 the broadest context possible. Future research directions may also be highlighted.

270 5. Conclusions

271 The incorporation of plant debris at the end of the crop cycle using biosolarization has been
272 shown to be an efficient practice for the management of this residue, solving the problem of
273 handling crop residues by offering a technique that respects the environment, benefits the circular
274 economy and provides a reference for horticultural production systems, even for the transition to

275 organic farming. The addition of organic amendments provides the necessary nutrients for the
276 correct development of a greenhouse tomato culture (5–6 months), achieving the same yield as a
277 conventional inorganic fertilization system and, in addition, maintaining the main organoleptic
278 properties of the fruit and being economically beneficial for growers. Future research should be
279 focused on determining the impact on the water footprint due to improved soil structure as a result
280 of organic matter, an aspect of vital importance for the protected agriculture of the Mediterranean
281 basin.

282 **Author Contributions:** Conceptualization, J.C.T.-M. and C.R.-O; methodology, J.I.M.-G and C.R.-O;
283 investigation, C.R.-O. and P.G.-R.; resources, C.A.G.; writing—original draft preparation, P.G.-R.;
284 writing—review and editing, J.I.M.-G and M.dC.-G.; supervision, J.I.M.-G and M.dC.-G.; project
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291 References

- 292 1. Castilla, N. *Greenhouse Technology and Management*, 2nd ed.; CABI: Wallingford, United Kingdom, 2013;
293 1-335; ISBN: 9781780641034 . Available online: <https://www.cabi.org/bookshop/book/9781780641034>
294 (accessed on 09.11.2018).
- 295 2. Cabrera, A.; Uclés, D.; Aguera, T.; de la Cruz, E. Análisis de la campaña hortofrutícola de Almería:
296 Campaña 2016/2017. *Editorial Fundación Cajamar*, **2017**, 1, 1-59.
297 Available online:
298 <http://www.publicacionescajamar.es/series-tematicas/informes-coyuntura-analisis-de-campana/analisis-de-la-campana-hortofruticola-de-almeria-campana-2016-2017/> (accessed on 09.11.2018).
- 299 3. Lamichhane, J.R. Pesticide use and risk reduction in European farming systems with IPM: An
300 introduction to the special issue. *Crop Prot.* **2017**, *97*, 1-6, doi:<https://doi.org/10.1016/j.cropro.2017.01.017>.
301 Available online:
302 <https://www.sciencedirect.com/science/article/pii/S0261219417300261> (accessed on 09.11.2018).
- 303 4. Ramos, C.; Agut, A.; Lidón, A.L. Nitrate leaching in important crops of the Valencian Community region
304 (Spain). *Environ. Pollut.* **2002**, *118*, 215-223. doi:[https://doi.org/10.1016/S0269-7491\(01\)00314-1](https://doi.org/10.1016/S0269-7491(01)00314-1).
305 Available online: <https://www.ncbi.nlm.nih.gov/pubmed/11939284> (accessed on 09.11.2018).
- 306 5. Vázquez, N.; Pardo, A.; Suso, M.L.; Quemada, M. Drainage and nitrate leaching under processing tomato
307 growth with drip irrigation and plastic mulching. *Agric Ecosyst Environ.* **2006**, *112*, 313-323.
308 doi:<https://doi.org/10.1016/j.agee.2005.07.009>.
309 Available online:
310 <https://www.sciencedirect.com/science/article/pii/S0167880905003816> (accessed on 09.11.2018).
- 311 6. Thompson, R.B.; Martínez-Gaitan, C.; Gallardo, M.; Giménez, C.; Fernández, M.D. Identification of
312 irrigation and N management practices that contribute to nitrate leaching loss from an intensive
313 vegetable production system by use of a comprehensive survey. *Agric. Water. Manag.* **2007**, *89*, 261-274.
314 doi:<https://doi.org/10.1016/j.agwat.2007.01.013>.
315 Available online:
316 <https://www.sciencedirect.com/science/article/pii/S0378377407000376?via%3Dihub> (accessed on
317 09.11.2018).
318

- 319 7. Yasuor, H.; Ben-Gal, A.; Yermiyahu, U.; Beit-Yannai, E.; Cohen, S. Nitrogen management of greenhouse
320 pepper production: agronomic, nutritional, and environmental implications. *HortScience* **2013**, *48*,
321 1241-1249.
322 Available online: <http://hortsci.ashspublications.org/content/48/10/1241.full> (accessed on 09.11.2018).
- 323 8. Junta de Andalucía. Estrategia de gestión de restos vegetales en la horticultura de Andalucía. *Consejería de*
324 *Agricultura y Pesca y Desarrollo Rural; Consejería de Medio Ambiente y Ordenación del Territorio* **2016**, *1*, 1-45.
325 Available online:
326 [https://www.juntadeandalucia.es/export/drupaljda/Lineas_actuacion_materia_gestion_restos_vegetales_](https://www.juntadeandalucia.es/export/drupaljda/Lineas_actuacion_materia_gestion_restos_vegetales_horticultura_Andalucia.pdf)
327 [horticultura_Andalucia.pdf](https://www.juntadeandalucia.es/export/drupaljda/Lineas_actuacion_materia_gestion_restos_vegetales_horticultura_Andalucia.pdf) (accessed on 09.11.2018).
- 328 9. López-Hernández, J.C.; Pérez-Martínez, C.; Acien-Fernández, F.G. Residuos vegetales procedentes de los
329 invernaderos de Almería. *Publicaciones Cajamar* **2016**, *17*, 1-9.
330 Available online:
331 <https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/formacion/actividades-de-transferencia/017>
332 [-restos-vegetales-1466406472.pdf](https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/formacion/actividades-de-transferencia/017) (accessed on 09.11.2018).
- 333 10. Kumar, V.; Abdul-Baki, A.; Anderson, J.D.; Mattoo, A.K. Cover crop residues enhance growth, improve
334 yield, and delay leaf senescence in greenhouse-grown tomatoes. *HortScience* **2005**, *40*, 1307-1311.
335 Available online: <http://hortsci.ashspublications.org/content/40/5/1307.abstract> (accessed on 09.11.2018).
- 336 11. Marín-Guirao, J.I.; Tello, J.C.; Díaz, M.; Boix, A.; Ruiz, C.A.; Camacho, F. Effect of greenhouse soil
337 bio-disinfection on soil nitrate content and tomato fruit yield and quality. *Soil Res.* **2016**, *54*, 200-206,
338 doi:<https://doi.org/10.1071/SR15106>.
339 Available online: <http://www.publish.csiro.au/SR/SR15106> (accessed on 09.11.2018).
- 340 12. Bello Pérez, A.; González-Pérez, J.A.; Tello, J.C. La biofumigación como alternativa a la desinfección de
341 suelos. *Horticultura Internacional* **1997**, *43*, 41-43.
342 <http://digital.csic.es/bitstream/10261/84815/1/La%20biofumigaci%C3%B3n%20como%20alternativa.pdf>
343 (accessed on 09.11.2018).
- 344 13. Kirkegaard, J.A.G., P.A.; Desmarchelier, J.M.; Angus, J.F. Biofumigation - using Brassica species to control
345 pests and diseases in horticulture and agriculture. *Proceedings 9th Australian Research Assembly on Brassica*
346 **1993**, *1*, 77-82.
347 Available online:
348 <https://publications.csiro.au/rpr/pub?list=BRO&pid=procite:1ab24273-efdb-43d2-a034-071ccfa128c4>
349 (accessed on 09.11.2018).
- 350 14. Katan, J. Solar heating (solarization) of soil for control of soilborne pests. *Annu. Rev. Phytopathol.* **1981**, *19*,
351 211-236, doi:10.1146/annurev.py.19.090181.001235.
352 Available online:
353 <https://www.annualreviews.org/doi/abs/10.1146/annurev.py.19.090181.001235> (accessed on 09.11.2018).
- 354 15. Scopa, A.; Candido, V.; Dumontet, S.; Miccolis, V. Greenhouse solarization: effects on soil microbiological
355 parameters and agronomic aspects. *Sci. Hort.* **2008**, *116*, 98-103. doi:10.1016/j.scienta.2007.11.008.
356 Available online:
357 <https://www.sciencedirect.com/science/article/pii/S0304423807004037> (accessed on 09.11.2018).
- 358 16. Mauromicale, G.; Longo, A.M.G.; Lo Monaco, A. The effect of organic supplementation of solarized soil
359 on the quality of tomato fruit. *Sci. Hort.* **2011**, *129*, 189-196. doi:10.1016/j.scienta.2011.03.024.
360 Available online:
361 <https://www.sciencedirect.com/science/article/pii/S0304423811001324> (accessed on 09.11.2018).

- 362 17. Chan, K.Y.; Heenan, D.P. The influence of crop rotation on soil structure and soil physical properties
363 under conventional tillage. *Soil Tillage Res.* **1996**, *37*, 113-125, doi:10.1016/0167-1987(96)01008-2.
364 Available online:
365 <https://www.sciencedirect.com/science/article/pii/0167198796010082> (accessed on 09.11.2018).
- 366 18. McGuire, A.M. Mustard Green Manures Replace Fumigant and Improve Infiltration in Potato Cropping
367 System. *Crop Management* **2003**, *2*, 1-6, doi:10.1094/cm-2003-0822-01-rs.
368 Available online: <https://dl.sciencesocieties.org/publications/cm/abstracts/2/1/2003-0822-01-RS> (accessed
369 on 09.11.2018).
- 370 19. Bailey, K.L.; Lazarovits, G. Suppressing soil-borne diseases with residue management and organic
371 amendments. *Soil Till. Res.* **2003**, *72*, 169-180, doi:[https://doi.org/10.1016/S0167-1987\(03\)00086-2](https://doi.org/10.1016/S0167-1987(03)00086-2).
372 Available online:
373 <https://www.sciencedirect.com/science/article/pii/S0167198703000862> (accessed on 09.11.2018).
- 374 20. Thorup-Kristensen, K.; Magid, J.; Jensen, L.S. Catch crops and green manures as biological tools in
375 nitrogen management in temperate zones. *Adv. Agron.* **2003**, *79*, 227-302,
376 doi:10.1016/S0065-2113(02)79005-6.
377 Available online: <http://www.orgprints.org/107/> (accessed on 09.11.2018).
- 378 21. Stapleton, J.J.; Quick, J.; Devay, J.E. Soil solarization - effects on soil properties, crop fertilization and
379 plant-growth. *Soil Biol. Biochem.* **1985**, *17*, 369-373, doi:10.1016/0038-0717(85)90075-6.
380 Available online:
381 <https://www.sciencedirect.com/science/article/abs/pii/0038071785900756> (accessed on 09.11.2018).
- 382 22. Lazzeri, L.; Malaguti, L.; Cinti, S.; Ugolini, L.; De Nicola, G.R.; Bagatta, M.; Casadei, N.; D'Avino, L.;
383 Matteo, R.; Patalano, G. The brassicaceae biofumigation system for plant cultivation and defence. An
384 italian twenty-year experience of study and application. *Acta Hort.* **2013**, *1005*, 375-382,
385 doi:10.17660/ActaHortic.2013.1005.44
386 Available online: https://www.actahort.org/books/1005/1005_44.htm (accessed on 09.11.2018).
- 387 23. Reddy, P.P. *Biofumigation and Solarization for Management of Soil-Borne Plant Pathogens*, 1st ed.; Scientific
388 Publishers: Jodhpur, India, 2011; 1-431; ISBN: 9788172336974.
389 Available online:
390 <http://www.scientificpub.com/book-details/Biofumigation-and-Solarization-for-Management-of-Soil-Bor>
391 [ne-Plant-Pathogens-151.html](http://www.scientificpub.com/book-details/Biofumigation-and-Solarization-for-Management-of-Soil-Bor) (accessed on 09.11.2018).
- 392 24. Willer, H.; Lernoud, J. The world of organic agriculture. Statistics and emerging trends. *Research Institute*
393 *of Organic Agriculture FiBL and IFOAM Organics International*, **2016**, *1*, 1-340.
394 Available online:
395 <https://shop.fibl.org/CHde/mwdownloads/download/link/id/785/?ref=1> (accessed on 09.11.2018).
- 396 25. Valera, D.L.; Belmonte, L.J.; Molina-Aiz, F.D.; López, A.; Camacho, F. The greenhouses of Almería, Spain:
397 technological analysis and profitability. *Acta Hort.* **2017**, *1170*, 219-226,
398 doi:10.17660/ActaHortic.2017.1170.25
399 Available online: https://www.actahort.org/books/1170/1170_25.htm (accessed on 09.11.2018).
- 400 26. Bretones, C. El enarenado. In *Técnicas de producción en cultivos protegidos*, 1st ed.; Ed. Instituto Cajamar:
401 Madrid, España, 2003, Volume 1, pp. 110-118; ISBN: 84-95531-15-1.
402 Available online:
403 <http://www.publicacionescajamar.es/pdf/series-tematicas/agricultura/tecnicas-de-produccion-en-cultivo>
404 [s-2.pdf](http://www.publicacionescajamar.es/pdf/series-tematicas/agricultura/tecnicas-de-produccion-en-cultivo) (accessed on 09.11.2018).

- 405 27. Contreras París, J.; Baeza Cano, R.J.; Segura Pérez, M. Cuantificación de los nutrientes aportados al suelo
406 por la incorporación de los restos de los cultivos hortícolas en invernaderos. *Agricultura y ganadería*
407 *ecológica* **2015**, *11*, 18-19.
408 Available online:
409 [https://www.agroecologia.net/recursos/publicaciones/actas/cd-actas-xicongresoseae/actas/comunicacion](https://www.agroecologia.net/recursos/publicaciones/actas/cd-actas-xicongresoseae/actas/comunicaciones/67-cuantificacion-nutrientes-contreras-resumen.pdf)
410 [es/67-cuantificacion-nutrientes-contreras-resumen.pdf](https://www.agroecologia.net/recursos/publicaciones/actas/cd-actas-xicongresoseae/actas/comunicaciones/67-cuantificacion-nutrientes-contreras-resumen.pdf) (accessed on 09.11.2018).
- 411 28. Moreno Casco, J.; Moral Herrero, R. *Compostaje*, 1st ed.; Mundi-Prensa: Madrid, España, 2008; 1-572;
412 ISBN: 9788484763468.
413 Available online:
414 <https://www.mundiprensa.com/catalogo/9788484763468/compostaje> (accessed on 09.11.2018).
- 415 29. Casas Castro, A.; Casas Barba, E. Análisis de suelo-agua-planta y su aplicación en la nutrición de los
416 cultivos hortícolas en la zona del sureste peninsular. *Publicaciones Cajamar* **1999**, *1*, 1-249.
417 Available online:
418 [http://www.publicacionescajamar.es/series-tematicas/agricultura/analisis-de-suelo-agua-planta-y-su-apli-](http://www.publicacionescajamar.es/series-tematicas/agricultura/analisis-de-suelo-agua-planta-y-su-aplicacion-en-la-nutricion-de-cultivos-hortícolas-en-la-zona-peninsular/)
419 [cacion-en-la-nutricion-de-cultivos-hortícolas-en-la-zona-peninsular/](http://www.publicacionescajamar.es/series-tematicas/agricultura/analisis-de-suelo-agua-planta-y-su-aplicacion-en-la-nutricion-de-cultivos-hortícolas-en-la-zona-peninsular/) (accessed on 09.11.2018).
- 420 30. Fernández, P.; Pascual, J.; Lacasa, A. Potencial de lixiviación de nitratos de la técnica de biosolarización en
421 suelos de invernaderos de pimiento. *Sociedad Española de Ciencias de Hortícolas* **2014**, *66*, 107-115.
422 Available online:
423 [http://www.sech.info/ACTAS/Acta%20n%C2%BA%2066.%20V%20Jornadas%20del%20grupo%20de%20](http://www.sech.info/ACTAS/Acta%20n%C2%BA%2066.%20V%20Jornadas%20del%20grupo%20de%20fertilizaci%C3%B3n/Sesi%C3%B3n%201.%20Cultivos%20Hort%C3%ADcolas/Potencial%20de%20lixiviaci%C3%B3n%20de%20nitratos%20de%20la%20t%C3%A9cnica%20de%20biosolarizaci%C3%B3n%20en%20suelos%20de%20invernaderos%20de%20pimiento.pdf)
424 [fertilizaci%C3%B3n/Sesi%C3%B3n%201.%20Cultivos%20Hort%C3%ADcolas/Potencial%20de%20lixivi-](http://www.sech.info/ACTAS/Acta%20n%C2%BA%2066.%20V%20Jornadas%20del%20grupo%20de%20fertilizaci%C3%B3n/Sesi%C3%B3n%201.%20Cultivos%20Hort%C3%ADcolas/Potencial%20de%20lixiviaci%C3%B3n%20de%20nitratos%20de%20la%20t%C3%A9cnica%20de%20biosolarizaci%C3%B3n%20en%20suelos%20de%20invernaderos%20de%20pimiento.pdf)
425 [ci%C3%B3n%20de%20nitratos%20de%20la%20t%C3%A9cnica%20de%20biosolarizaci%C3%B3n%20en%](http://www.sech.info/ACTAS/Acta%20n%C2%BA%2066.%20V%20Jornadas%20del%20grupo%20de%20fertilizaci%C3%B3n/Sesi%C3%B3n%201.%20Cultivos%20Hort%C3%ADcolas/Potencial%20de%20lixiviaci%C3%B3n%20de%20nitratos%20de%20la%20t%C3%A9cnica%20de%20biosolarizaci%C3%B3n%20en%20suelos%20de%20invernaderos%20de%20pimiento.pdf)
426 [20suelos%20de%20invernaderos%20de%20pimiento.pdf](http://www.sech.info/ACTAS/Acta%20n%C2%BA%2066.%20V%20Jornadas%20del%20grupo%20de%20fertilizaci%C3%B3n/Sesi%C3%B3n%201.%20Cultivos%20Hort%C3%ADcolas/Potencial%20de%20lixiviaci%C3%B3n%20de%20nitratos%20de%20la%20t%C3%A9cnica%20de%20biosolarizaci%C3%B3n%20en%20suelos%20de%20invernaderos%20de%20pimiento.pdf) (accessed on 09.11.2018).
- 427 31. Chen, Y.; Katan, J.; Gamliel, A.; Aviad, T.; Schnitzer, M. Involvement of soluble organic matter in
428 increased plant growth in solarized soils. *Biol. Fertil. Soils* **2000**, *32*, 28-34, doi:10.1007/s003740000209.
429 Available online: <https://link.springer.com/article/10.1007/s003740000209> (accessed on 09.11.2018).
- 430 32. Guerrero, M.M.; Martínez, M.A.; Ros, C.; Martínez, M.C.; Bello, A.; Lacasa, A. Biosolarización y
431 biofumigación para la producción de pimiento ecológico en invernadero. *Sociedad Española de Agricultura*
432 *Ecológica*, **2006**, *103*, 1-8.
433 Available online:
434 [https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Za-](https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Zaragoza/Ponencias/103%20Guerrero%20Com-%20Biosolarizaci%C3%B3n.pdf)
435 [ragoza/Ponencias/103%20Guerrero%20Com-%20Biosolarizaci%C3%B3n.pdf](https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Zaragoza/Ponencias/103%20Guerrero%20Com-%20Biosolarizaci%C3%B3n.pdf) (accessed on 09.11.2018).
- 436 33. Martínez, M.A.; Guerrero, M.M.; Martínez, M.C.; Ros, C.; Lacasa, A.; Tello, J.C. Efecto de la
437 biosolarización reiterada sobre la microbiota fúngica en cultivos de pimiento. *Sociedad Española de*
438 *Agricultura Ecológica*, **2006**, *212*, 1-10.
439 Available online:
440 [https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Za-](https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Zaragoza/Ponencias/212%20Martinez%20Com-%20Efecto.pdf)
441 [ragoza/Ponencias/212%20Martinez%20Com-%20Efecto.pdf](https://www.agroecologia.net/recursos/publicaciones/publicaciones-online/2006/CD%20Congreso%20Zaragoza/Ponencias/212%20Martinez%20Com-%20Efecto.pdf) (accessed on 09.11.2018).
- 442 34. Díez-Rojo, M.; López-Pérez, J.; Urbano-Terrón, P.; Bello, A. *Biodesinfección de suelos y manejo agronómico*.
443 Ministerio de Medio Ambiente y Medio Rural y Marino: Madrid, España, 2010; 1-407; NIPO:770.10.292.0.
444 Available online:
445 [https://www.miteco.gob.es/va/calidad-y-evaluacion-ambiental/publicaciones/libro%20de%20biodesinfec-](https://www.miteco.gob.es/va/calidad-y-evaluacion-ambiental/publicaciones/libro%20de%20biodesinfecci%C3%B3n_tcm39-185072.pdf)
446 [ci%C3%B3n_tcm39-185072.pdf](https://www.miteco.gob.es/va/calidad-y-evaluacion-ambiental/publicaciones/libro%20de%20biodesinfecci%C3%B3n_tcm39-185072.pdf) (accessed on 09.11.2018).

- 447 35. Fernández-Bayo, J.D.; Achmon, Y.; Harrold, D.R.; McCurry, D.G.; Hernandez, K.; Dahlquist-Willard,
448 R.M.; Stapleton, J.J.; VanderGheynst, J.S.; Simmons, C.W. Assessment of Two Solid Anaerobic Digestate
449 Soil Amendments for Effects on Soil Quality and Biosolarization Efficacy. *J. Agric. Food Chem.* **2017**, *65*,
450 3434-3442, doi:10.1021/acs.jafc.6b04816.
451 Available online: <https://www.ncbi.nlm.nih.gov/pubmed/28409935> (accessed on 09.11.2018).
- 452 36. Iapichino, G.; Puleo, L.; Vetrano, F.; Sciortino, A. Effects of Solarization and Biofumigation on Tomato
453 Greenhouse Production in the Southern Coast of Sicily. *Acta Hort.* **2008**, *801*, 1557-1562, doi:
454 10.17660/ActaHortic.2008.801.192.
455 Available online: https://www.actahort.org/books/801/801_192.htm (accessed on 09.11.2018).
- 456 37. Porras, M.; Barrau, C.; Romero, E.; Zurera, C.; Romero, F. Effect of Biofumigation with *Brassica carinata*
457 and Soil Solarization on *Phytophthora* spp. and Strawberry Yield. *Acta Hort.* **2008**, *842*: 969-972, doi:
458 10.17660/ActaHortic.2009.842.215.
459 Available online: https://www.actahort.org/books/842/842_215.htm (accessed on 09.11.2018).
- 460 38. Garibaldi, A.; Gilardi, G.; Clematis, F.; Gullino, M.L.; Lazzeri, L.; Malaguti, L. Effect of Green Brassica
461 Manure and Brassica Defatted Seed Meals in Combination with Grafting and Soil Solarization against
462 *Verticillium* Wilt of Eggplant and *Fusarium* Wilt of Lettuce and Basil. *Acta Hort.* **2010**, *883*, 295-302,
463 doi:10.17660/ActaHortic.2010.883.36.
464 Available online: https://www.actahort.org/books/883/883_36.htm (accessed on 09.11.2018).
- 465 39. Lombardo, S.; Longo, A.M.G.; Lo Monaco, A.; Mauromicale, G. The effect of soil solarization and
466 fumigation on pests and yields in greenhouse tomatoes. *Crop Prot.* **2012**, *37*, 59-64,
467 doi:10.1016/j.cropro.2012.02.010.
468 Available online:
469 <https://www.sciencedirect.com/science/article/pii/S0261219412000373> (accessed on 09.11.2018).
- 470 40. Hansen, Z.R.; Keinath, A.P. Increased pepper yields following incorporation of biofumigation cover
471 crops and the effects on soilborne pathogen populations and pepper diseases. *Appl. Soil Ecol.* **2013**, *63*,
472 67-77, doi:10.1016/j.apsoil.2012.09.007.
473 Available online:
474 <https://www.sciencedirect.com/science/article/pii/S0929139312002302> (accessed on 09.11.2018).
- 475 41. Suja, G.; Byju, G.; Jyothi, A.N.; Veena, S.S.; Sreekumar, J. Yield, quality and soil health under organic vs
476 conventional farming in taro. *Sci. Hort.* **2017**, *218*, 334-343, doi:10.1016/j.scienta.2017.02.006.
477 Available online: <https://www.sciencedirect.com/science/article/pii/S0304423817300912> (accessed on
478 09.11.2018).
- 479 42. Achmon, Y.; Sade, N.; Wilhelmi, M.; Fernandez-Bayo, J.D.; Harrold, D.R.; Stapleton, J.J.; VanderGheynst,
480 J.S. Effects of Short-Term Biosolarization Using Mature Compost and Industrial Tomato Waste
481 Amendments on the Generation and Persistence of Biocidal Soil Conditions and Subsequent Tomato
482 Growth. *J. Agric. Food Chem.* **2018**, *66*, 5451-5461, doi:10.1021/acs.jafc.8b00424.
483 Available online: <https://www.ncbi.nlm.nih.gov/pubmed/29763301> (accessed on 09.11.2018).
- 484 43. Ros, M.; Garcia, C.; Hernandez, M.T.; Lacasa, A.; Fernandez, P.; Pascual, J.A. Effects of biosolarization as
485 methyl bromide alternative for *Meloidogyne incognita* control on quality of soil under pepper. *Biol. Fertil.*
486 *Soils* **2008**, *45*, 37, doi:10.1007/s00374-008-0307-1.
487 Available online: <https://link.springer.com/article/10.1007/s00374-008-0307-1> (accessed on 09.11.2018).
- 488 44. Mauromicale, G.; Monaco, A.L.; Longo, A.M.G. Improved efficiency of soil solarization for growth and
489 yield of greenhouse tomatoes. *Agron. Sustain. Dev.* **2010**, *30*, 753-761, doi:10.1051/agro/2010015.

- 490 Available online: <https://link.springer.com/article/10.1051/agro/2010015> (accessed on 09.11.2018).
- 491 45. Nuñez-Zofío, M.; Larregla del Palacio, S.; Garbisu, C. Repeated biodesinfection controls the incidence of
- 492 *Phytophthora* root and crown rot of pepper while improving soil quality. *Spanish Journal of Agricultural*
- 493 *Research* **2012**, *10*, 794-805, doi:10.5424/sjar/2012103-571-11.
- 494 Available online: <http://revistas.inia.es/index.php/sjar/article/view/2342> (accessed on 09.11.2018).
- 495 46. López-Aranda, J.M.; Miranda, L.; Domínguez, P.; Soria, C.; Pérez-Jiménez, R.M.; Zea, T.; Talavera, M.;
- 496 Velasco, L.; Romero, F.; De Los Santos, B., et al. Soil biosolarization for strawberry cultivation. *Acta Horti-*
- 497 **2012**, *926*: 407-413, doi: 10.17660/ActaHortic.2012.926.57.
- 498 Available online: https://www.actahort.org/books/926/926_57.htm (accessed on 09.11.2018).
- 499 47. Pane, C.; Vilecco, D.; Pentangelo, A.; Lahoz, E.; Zaccardelli, M. Integration of soil solarization with
- 500 *Brassica carinata* seed meals amendment in a greenhouse lettuce production system. *Acta Agric. Scand.*
- 501 *Sect. B Soil Plant Sci.* **2012**, *62*, 291-299, doi:10.1080/09064710.2011.613850.
- 502 Available online:
- 503 <https://www.tandfonline.com/doi/abs/10.1080/09064710.2011.613850> (accessed on 09.11.2018).
- 504 48. Guerrero, M.; Lacasa, C.; Ros, C.; Martínez, V.; Fenoll, J.; Torres, J.; Beltrán, C.; Fernández, P.; Bello, A.;
- 505 Lacasa, A. Pellets de brasicas como enmiendas para biosolarización de invernaderos de pimiento. *XII*
- 506 *Congreso Nacional de Ciencias Hortícolas* **2009**, *1*, 1-6.
- 507 Available online:
- 508 <http://www.sech.info/ACTAS/Acta%20n%C2%BA%2054.%20VI%20Congreso%20Ib%C3%A9rico%20de%20Ciencias%20Hort%C3%ADcolas.%20XII%20Congreso%20Nacional%20de%20Ciencias%20Hort%C3%ADcolas/Comunicaciones/Pellets%20de%20brasicas%20como%20enmiendas%20para%20biosolarizaci%C3%B3n%20de%20invernaderos%20de%20pimiento.pdf> (accessed on 09.11.2018).
- 511
- 512 49. Domene Ruiz, M.A., Segura Rodriguez M. Parámetros de calidad externa en la industria agroalimentaria.
- 513 *Publicaciones Cajamar* **2014**, *1*, 1-12.
- 514 Available online:
- 515 [https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/003](https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/003-calidad-externa-1401191044.pdf)
- 516 [-calidad-externa-1401191044.pdf](https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/003-calidad-externa-1401191044.pdf) (accessed on 09.11.2018).
- 517 50. Domene Ruiz, M.A., Segura Rodriguez M. Parámetros de calidad interna en la industria agroalimentaria.
- 518 *Publicaciones Cajamar* **2014**, *1*, 1-18.
- 519 Available online:
- 520 [https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/005](https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/005-calidad-interna-1410512030.pdf)
- 521 [-calidad-interna-1410512030.pdf](https://www.cajamar.es/pdf/bd/agroalimentario/innovacion/investigacion/documentos-y-programas/005-calidad-interna-1410512030.pdf) (accessed on 09.11.2018).