

Article

Short-Term Effects of Changing Soil Management Practices on Soil Quality Indicators and Crop Yields in Greenhouses

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Abstract: The short-term responses of soil quality indicators are important for assessing the effects of new management practices and addressing threats to crop yields in greenhouses. The aim of this study was to assess, during three consecutive cropping seasons, the effect of a sustainable management package (CRTMP)—which includes the on-site reuse of greenhouse crop residues and tillage—in comparison with conventional management, based on fertigation only (CMP), on certain biochemical soil quality indicators and crop yields. CRTMP significantly increased ($p < 0.05$) the values of total organic carbon (TOC), particulate organic carbon (POC), light fraction (LF), water soluble organic carbon (WSOC), and dehydrogenase (DH) and β -glucosidase (GL) activities at a depth of 0–15 cm, as well as the mean concentration of nitrates in the soil solution. In addition, a significant Pearson's correlation ($p < 0.01$) found between the indicators suggested a balanced improvement of soil biological activity and nutritional soil state. Nonetheless, the significant ($p < 0.05$) increases in the mean concentration of chlorides in the soil solution and electrical conductivity ($p < 0.05$) increased the risk of salinization, which may have affected the concentration of nitrates in the petiole sap and total production in CRTMP, which were significantly lower than in CMP. Nevertheless, the proportion of premium product was significantly higher in CRTMP, while the proportion of non-commercial production decreased.

Keywords: organic carbon fractions; soil enzymes; crop management; soil solution

1. Introduction

Greenhouse agriculture, based on production and profitability, is becoming widespread in the Mediterranean region, with an increasing socioeconomic impact [1]. The province of Almería (SE Spain), with 31,034 ha, has the highest concentration of greenhouses, most of which are low or medium cost structures with plastic covers [2,3], dedicated to the cultivation of horticultural species. Conventional greenhouse management practices are characterized, in most cases, by the excessive use of agrochemicals and irrigation water [4,5], which, along with the absence of organic inputs or tillage, tends to make the soil lose quality in the long term [6–9] and has caused a series of environmental problems associated with nitrate leaching [10,11] or with the accumulation of a huge amount of crop residues at the end of the cropping season [12]. These problems, coupled with the current situation of the instability of prices perceived by the farmers, which sometimes do not cover production costs [1], endanger the future sustainability of the system.

It is, therefore, becoming necessary to introduce alternative management packages that will enable the system to reduce its dependence on external inputs [12], while optimizing resources and reducing

waste generation [8,13], mainly crop residues. However, agricultural greenhouse systems demand high investments per crop season that need to be compensated with income in a very short period of time; therefore, it is particularly important to carefully select indicators that allow, in the short term, an accurate assessment of the impact of new management practices on soil and crops. Several studies in outdoor and greenhouse farming have shown that the contribution of organic materials can cause significant changes in biochemical properties and alter microbial activity, improving soil quality [14–17], and has been used to meet the N demands of the crops [18]. Del Moral et al. [19], after a long-term trial, demonstrated that several soil physical properties were improved in organic managed greenhouses fertilized with manure, and that total organic carbon, total nitrogen and the cation exchange capacity were increased in comparison with conventional management. However, for the correct management of intensive crops in greenhouses, more information regarding the evolution of different soil quality indicators during cultivation and their impact on the harvest is necessary, covering the existing scientific information deficit for this agrosystem, while providing useful and convincing information to stakeholders.

Soil quality indicators provide information on the properties, characteristics and processes related to the soil functions and soil fertility [20–23]. Among them, biochemical indicators, because of their high sensitivity in short term, could be useful to assess the impact of any new management practice.

Although total organic carbon is the most widely used indicator to assess soil quality, soil productivity and agricultural sustainability [24,25], it is generally accepted that the change in its content is not very sensitive in the short and medium term [26,27], so labile fractions—which often include particulate organic carbon (POC), light fraction (LF), and water-soluble organic carbon (WSOC) [28]—have been used as short-term indicators after changing soil management practices [29–34]. POC, LF and WSOC are three fractions considered active in the nutrient cycles, readily available for microbial breakdown and closely associated with nutrient supply to crops [35,36].

Enzymatic activities are also widely used indicators for their sensitivity to management change in agricultural systems, and provide information about soil microbial activity and biomass, the decomposition of organic matter, nutrient cycling, nutrient availability to crops, and other soil properties [37–42]. Among them, dehydrogenase (DH) and β -glucosidase (GL) are two frequently monitored enzymes [43,44]. DH activity, associated with the active fraction of the soil microbial community [45], reflects recent management or seasonal effects [46,47]; GL catalyzes the final step in the biodegradation of cellulose [48,49] and has been found to be sensitive to soil management, with changes being detectable within 1–3 years [50]. Finally, electrical conductivity (EC) is a frequently used indicator to assess the soil salinization risk [51], and periodic soil solution nitrate analysis is important to assess the availability of N to crops in greenhouse soils [52]. In this sense, the accumulation of chlorides and nitrates in soil solution can increase soil electrical conductivity and be harmful to crops [53,54].

The aim of this study was to assess the effects of a new management package—based on tillage, the use of crop residues and organic amendments with minimum inorganic fertilizer inputs—compared to a control with conventional management, during three consecutive cropping seasons, on the (i) short-term evolution of biochemical soil quality indicators, (ii) evolution of nitrate and chloride concentrations of the soil solution and (iii) crop yields in greenhouse systems.

2. Materials and Methods

2.1. Location and Description of Greenhouses

The experimental work was conducted during three consecutive cropping seasons (2015–2016, 2016–2017 and 2017–2018) in two adjacent and identical greenhouses (Greenhouse T0 and Greenhouse T1), built with the same artificial soil (Table 1) and having the same cultivation history, located in the Cajamar Experimental Station “Las Palmerillas”, El Ejido, Almería, SE Spain (36°48′ N, 2°43′ W and 151 m elevation). The dimensions of each of them were 24 m long by 18 m wide, oriented

East to West. The greenhouses had a height of 2.9 m on the sidebands and 4.2 m on the ridge. The covering of the greenhouses was low density polyethylene (LDPE) tri-laminated film (200 μm thickness). The greenhouses had passive ventilation through two roll-up side windows (2 m height \times 22 m long) on the north and south sides, and a folding top window. All windows were covered by a 20 \times 10 cm^2 insect screen and their opening and closing was controlled by an automatic controller (Priva WeatherStation, Priva, LC De Lier, The Netherlands).

Table 1. Soil properties of each greenhouse before starting the study at a depth in the 0–15 cm range.

	Greenhouse T0	Greenhouse T1
Soil Texture (USDA)	Silty clay loam	Silty clay loam
TOC	6.21 (1.10)	6.47 (1.48)
POC	0.72 (0.33)	0.80 (0.36)
WSOC	0.05 (0.01)	0.06 (0.01)
LF	0.18 (0.12)	0.40 (0.24)
DH	2.46 (0.96)	2.84 (1.07)
GL	77.34 (14.60)	89.32 (18.28)
TN	1.10 (0.35)	1.70 (0.40)
EC	0.50 (0.15)	0.75 (0.15)
pH	8.49 (0.04)	8.45 (0.04)

The data show values from five samples obtained in randomly selected crop lines in each greenhouse. There were no significant differences in soil properties ($p < 0.05$), according to Mann-Whitney U test. TOC: total organic carbon (g kg^{-1} soil); POC: particulate organic carbon (g kg^{-1} soil); WSOC: water-soluble organic carbon (g kg^{-1} soil); LF: light fraction (g kg^{-1} soil); DH: dehydrogenase activity (mg TPF kg^{-1} soil day^{-1}); GL: β -glucosidase activity ($\mu\text{mol PNG kg}^{-1}$ soil h^{-1}); TN: total nitrogen (g kg^{-1} soil); EC: electrical conductivity (dS m^{-1}). EC and pH were determined in a 1:5 solution (v/v soil/water).

The irrigation system consisted of two independent irrigation sectors for each greenhouse, regulated with a flow meter (COTHINDRA, JANZ Group, CU 2520), with 24 paired dripper lines per sector and 16 integrated self-compensating drippers per line (Netafim, Tel Aviv, Israel), with a flow rate of 3.1 L h^{-1} . The distances were 1.5 m between the dripper lines (corridor), 0.5 m between the paired lines and 0.4 m between the drippers. The electrical conductivity (EC) of the irrigation water was 1.6 dS m^{-1} (Table 2), and the irrigation doses and frequencies were calculated with the PrHo program (© Cajamar Foundation) in order to reproduce irrigation similar to that achieved by the farmers in the area. Drainage was collected using two replicate free-draining lysimeters (4 m long \times 2 m wide \times 0.6 m deep) located at the southern side of each greenhouse.

Table 2. Average ion concentrations for irrigation water and nutrient solutions (mmol L^{-1}).

	Water	CMP	CRTMP
NO_3^-	0.15	11.02	3.49
H_2PO_4^-	0.00	1.56	0.00
$\text{SO}_4^{=}$	0.48	1.59	0.48
Cl^-	9.81	9.81	9.81
HCO_3^-	2.50	2.50	2.50
NH_4^+	0.00	0.19	0.00
K^+	0.14	6.24	0.14
Ca^{++}	2.23	4.84	2.77
Mg^{++}	2.05	2.23	2.05
Na^+	4.73	4.73	4.73

2.2. Description of Soil Management Packages

Greenhouse T0: conventional management package (CMP) or control. The distribution of soil horizons was the most common in the greenhouses in Almeria: from top to bottom, a coarse river sand layer as inorganic mulching (0–10 cm depth), silty clay loam soil layer imported from quarry (10–40 cm

depth) and sandy clay loam original soil (>40 cm depth). Fertilization and irrigation were similar to those in the commercial greenhouses in the area (fertigation) (Tables 2 and 3). The accumulated total nitrogen supplied in the form of inorganic fertilizers, in accordance with local practice regarding the typical N concentration used in fertigation of the sweet pepper, for the whole of the three cropping seasons, was 196.09 g m⁻². No crop residues or organic fertilizers were provided, nor was any tillage carried out. The total water contributed throughout the three cropping seasons was 1250.12 L m⁻². The total drainage collected was 308.91 L m⁻².

Table 3. The total amount of inorganic fertilizer provided in each management package for all three growing seasons (kg ha⁻¹).

	CMP	CRTMP
Ca(NO ₃) ₂	7690	1473
HNO ₃	2202	1658
KNO ₃	3613	0
K ₂ SO ₄	2043	0
MgSO ₄	540	0
KH ₂ PO ₄	2325	0
NH ₄ H ₂ PO ₄	273	0

Greenhouse T1: alternative management package based on the incorporation of crop residues, organic fertilizers and tillage (CRTMP), with the minimum use of inorganic fertilizers. In each cropping season, the soil was tilled to a depth of approximately 40 cm, with two cross passes using a rigid five double coil tines chisel powered by a Pasquali Siena K5.60 tractor. Then, organic amendments were added (Table 4): 2 kg m⁻² (fresh weight) of chopped sweet pepper crop residues from previous crop seasons and 2.5 kg m⁻² (fresh weight) of organic fertilizers (in the form of compost of horticultural crops (25%) and manure (75%)). The organic amendments were mixed at a depth of 15 cm using a self-propelled two-wheel cultivator (Pasquali 10.0 ZR, BCS Ibérica SAU, Terrasa, Spain). The estimated total nitrogen supplied in the form of crop residues and organic fertilizers throughout the three cropping seasons was 120.67 g m⁻² (Table 5). The total nitrogen supplied in the form of inorganic fertilizers throughout the three cropping seasons was 56.63 g m⁻² (Table 3). The inorganic fertilizer was applied to approximately equalize nitrogen inputs between the management packages. The total water contributed throughout the three cropping seasons was 1160.71 L m⁻². The total drainage collected was 170.06 L m⁻².

Table 4. The mean composition of the organic amendments applied to the soil at the beginning of the study in the sustainable management package (CRTMP).

		Bulk Density	TOC	TN	EC	pH	[Cl ⁻]
Organic amendments	Compost	0.48 (0.02)	210.40 (15.20)	18.00 (0.40)	28.10 (2.30)	7.71 (0.01)	35.40 (2.40)
	Manure	0.40 (0.01)	241.70 (14.15)	20.00 (0.18)	12.87 (1.12)	9.51 (0.01)	16.20 (1.50)
	Crop residues	0.56 (0.01)	307.20 (19.00)	13.90 (0.20)	18.40 (1.10)	9.52 (0.01)	7.80 (0.75)

Bulk density was measured over fresh organic amendments (g cm⁻³). TOC: total organic carbon (g kg⁻¹ dry weight); TN: total nitrogen (g kg⁻¹ dry weight); EC: electrical conductivity (dS m⁻¹); [Cl⁻]: chloride concentration (g kg⁻¹). EC and pH were determined in a 1:5 solution (v/v organic amendment/water). Standard deviations are shown in brackets (*n* = 3).

Table 5. Top: the total amount (over dry weight), total nitrogen and total organic carbon addition of crop residues and organic amendments (g m^{-2}) in CRTMP for all three cropping seasons. Bottom: the crop varieties, date of transplant and date of crop removal in each cropping season.

		Amount	TN Input	TOC Input
Crop residues		1320	18.35	405.50
Organic fertilizers	Compost	1240	22.32	260.90
	Manure	4000	80.00	966.80
TOTAL			120.67	1633.20
Crop Season				
		2015–2016	2016–2017	2017–2018
Crop varieties		Ebro	Canción	Melchor
Date of transplant		09/18/2015	07/28/2016	08/03/2017
Date of crop removal		05/03/2016	03/08/2017	04/09/2018

2.3. Description of the Crop Management

For each cropping season, after soil preparation, individual 5 week old seedlings of sweet pepper (*Capsicum annuum* L.) were transplanted at 6–8 cm from each dripper with a planting density of 2.4 plants m^{-2} . The crop varieties used and the dates of the transplant and crop removal are shown in Table 5. The crop management practices (crop training, pruning, pest management, etc.) in both greenhouses, apart from the soil management packages, were the same and followed the established local practice.

2.4. Soil Sampling

Five lines were randomly selected in each greenhouse, every month of each cropping season. From each selected line, three drippers were randomly selected, in each of which a soil subsample was taken at 0–15 cm depth to be mixed in a composite sample per line. In total, there were 135 composite samples per greenhouse. The subsamples were collected with an auger of 4.5 cm internal diameter, 10 cm from the dripper towards the corridor and avoiding the saline margin of the wet bulb, one day after irrigation. At the CMP, the sand mulch layer was removed before sampling. Once collected, the samples were kept field moist in polyethylene bags sealed at 4 °C until required.

2.5. Soil Analyses

Field moist samples were ground and sieved to 2 mm. Part of the sample was air dried and stored at room temperature to determine the EC.

Total organic carbon (TOC, g kg^{-1} soil) was determined in finely ground soil by wet oxidation [55]. POC was fractionated after dispersion of the sample with sodium hexametaphosphate and passing the sample through a 53 micrometer sieve [56]. LF was determined after density separation with potassium iodide (density 1.7 g cm^{-3}), so that the heavy fraction was deposited on the bottom and LF floated on the surface [57]. WSOC was determined after the filtration of the soil/water solution (1:2) [58]. Dehydrogenase activity (DH, $\text{mg TPF kg}^{-1} \text{ soil day}^{-1}$) was measured following the procedures described by Neogi et al. [59], and β -glucosidase activity (GL, $\mu\text{mol PNG kg}^{-1} \text{ soil h}^{-1}$) was measured following the procedures described by Eivazi and Tabatabai [60]. For DH activity, the concentration of triphenyl formazan (TPF), resulting from the reduction of chloride from 2-3-5-triphenyltetrazolium (TTC), was determined by spectrophotometry at 485 nm. GL activity was quantified based on the colorimetric measurement (410 nm) of p-nitrophenol released by β -glucosidase when the soil was incubated with a buffered solution of p-nitrophenyl- β -D-glucoside (PNG).

Electrical conductivity (EC, dS m^{-1}) was measured in soil [61] and organic amendments [62] in a 1:5 suspension (v/v), with a Crison 522 conductivity meter [63]. pH was measured in soil [64] and organic amendments [65] in a 1:5 suspension (v/v) with a Crison basic 20 pH-meter. The $[\text{NO}_3^-]$ and $[\text{Cl}^-]$

of soil solutions (mg L^{-1}) were measured in 1:5 soil suspensions (soil/water) by ion chromatography (ICS-1000 Dionex, Thermo Scientific, Waltham, Massachusetts, USA).

2.6. Measurements of Crop N Status

The $[\text{NO}_3^-]$ in petiole sap was analyzed every seven weeks throughout the cropping seasons. Six plants were randomly selected from the central crop lines in each greenhouse. The most recently expanded leaves of each of the six different plants in each management package were used; the petiole and fresh leaf blade were separated. Subsequently, the petioles of each plant were pressed, and the sap was obtained for analysis. The $[\text{NO}_3^-]$ was determined by means of selective electrodes, LAQUAtwin (Horiba Instruments Incorporated, California USA) [66].

2.7. Fruit Production

Four replicate areas of 3.2 m^2 , each with eight plants, were used to determine the fruit production. There were at least nine fruit harvests during each pepper crop. The first harvest was always done in green, and the rest of the harvests in red. For each fruit harvest, the fruit fresh weight per plant was determined. Fresh production was separated into marketable, with two categories, and non-marketable, according to locally used commercial criteria.

2.8. Statistical Analysis

Differences between management packages were determined ($p < 0.05$), treating them as independent samples, by means of non-parametric methods (Mann-Whitney U test), due to the lack of normality. Relationships between soil quality indicators were determined by Pearson's coefficient, and it was determined if this correlation was significant ($p < 0.01$). All statistical analyses were performed with the SPSS 25.0 and Excel software.

3. Results

3.1. Effects of the Application of the Management Packages on Soil Quality Indicators

The application of CRTMP significantly ($p < 0.05$) increased the values of all measured biochemical soil quality indicators in the 0–15 cm depth range, in which organic amendments and crop residues were added, except for WSOC at the beginning of the first two cropping seasons (Figure 1). These considerable increases were evident from the first cropping season in all measured indicators. In CRTMP, TOC had highest mean values at the beginning of the cropping seasons, after the recent tillage and incorporation of the organic amendments. The mean values of POC, LF and DH tended to increase during the second and third cropping seasons. In relation to GL, in CRTMP, values at the beginning of the first cropping season were lower than in the rest of the study, with the mean values established between 250.00 ± 42.83 and $342.75 \pm 77.68 \mu\text{mol PNG kg}^{-1} \text{ soil h}^{-1}$. The variability of the mean values in CRTMP were higher than with the CMP management package.

In CRTMP, the mean percentages of POC and LF relative to TOC were considerably high ($38.5\% \pm 13.4\%$ and $16.0\% \pm 6.3\%$, respectively), being more than half, and higher than in CMP ($17.2\% \pm 7.3\%$ and $2.5\% \pm 2.0\%$, respectively); the mean percentages of WSOC relative to TOC were relatively low in CRTMP ($3.3\% \pm 1.2\%$) and CMP ($2.4\% \pm 2.2\%$).

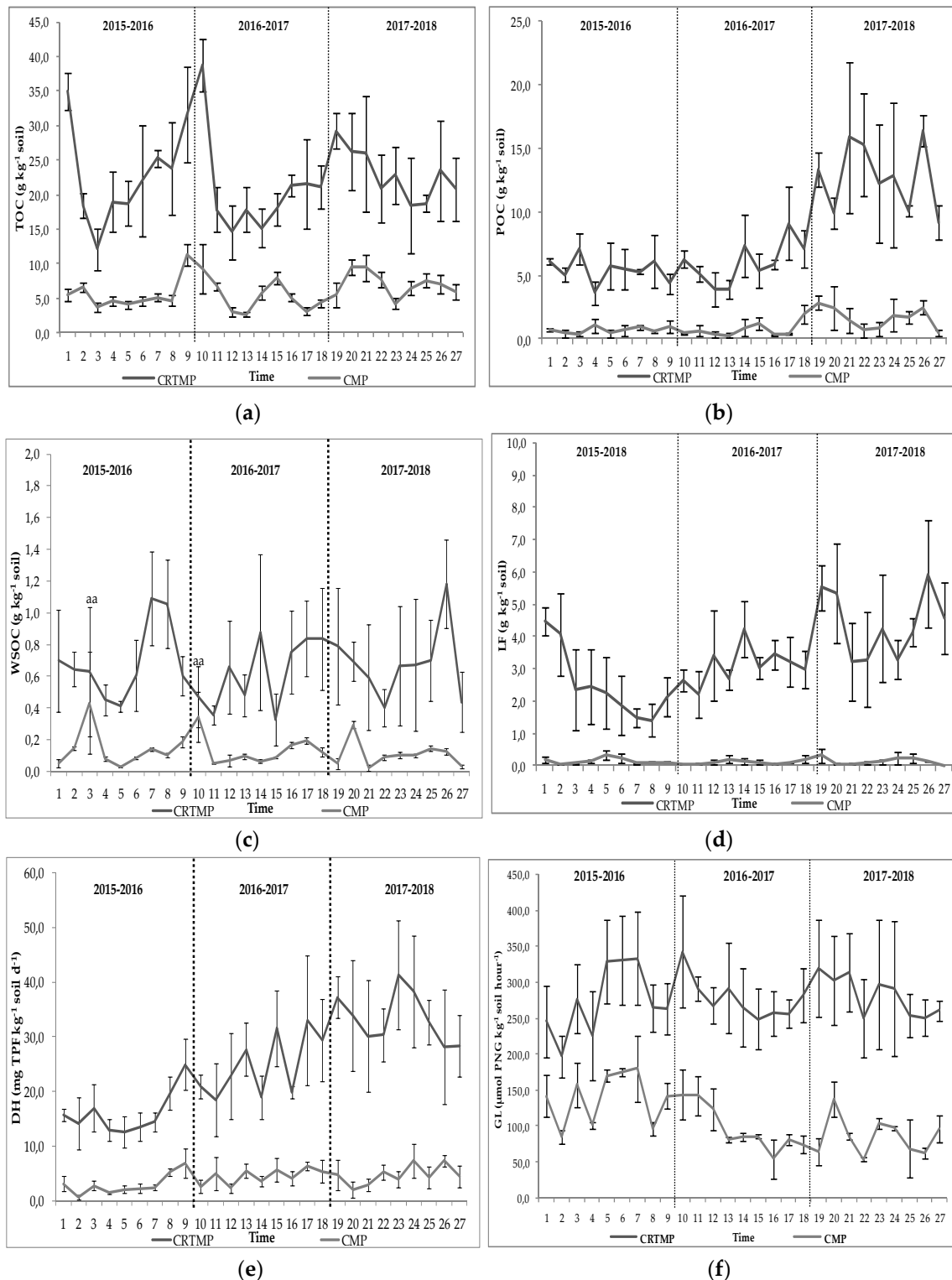


Figure 1. Growing season trends of (a) total organic carbon (TOC, g kg^{-1} soil), (b) particulate organic carbon (POC, g kg^{-1} soil), (c) water-soluble organic carbon (WSOC, g kg^{-1} soil), (d) light fraction (LF, g kg^{-1} soil), (e) dehydrogenase activity (DH, mg TPF kg^{-1} soil day^{-1}), and (f) β -glucosidase activity (GL, $\mu\text{mol PNG kg}^{-1}$ soil h^{-1}) in the two management packages (CMP and CRTMP) during the three study cropping seasons (2015–2016, 2016–2017 and 2017–2018). Values are means \pm SE. The same letters mean no significant differences ($p < 0.05$). The vertical dotted lines indicate the beginning of the cropping season and the incorporation of organic amendments. The correlative numbers on the X-axis refer to the months that had passed, with cultivation, since the beginning of the trials.

3.2. Electrical Conductivity, $[Cl^-]$ and $[NO_3^-]$ of the Soil Solution

The electrical conductivity, $[NO_3^-]$ and $[Cl^-]$ of the soil solution in CRTMP were significantly higher than with the CMP management package (Figure 2). In CRTMP, the highest mean values were detected at the beginning of the cropping seasons, with the recent incorporation of organic amendments, especially in the first cropping season.

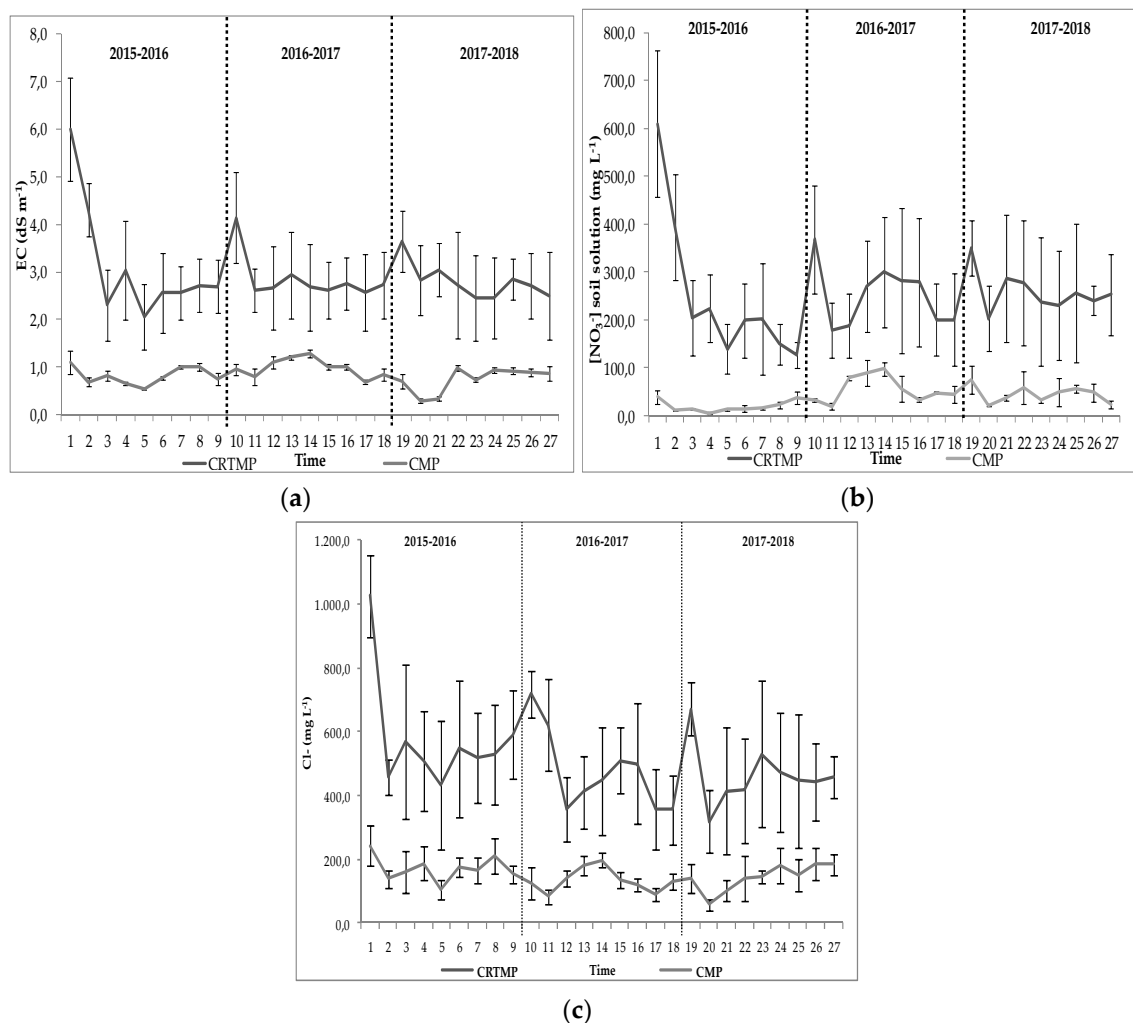


Figure 2. Growing season trends of (a) electrical conductivity (EC, dS m⁻¹), (b) $[NO_3^-]$ and (c) $[Cl^-]$ of the soil solution in the two management packages (CMP and CRTMP) during the three study cropping seasons (2015–2016, 2016–2017 and 2017–2018). Values are means \pm SE. There were significant differences in all months ($p < 0.05$). The vertical dotted lines indicate the beginning of the cropping season and the incorporation of organic amendments. EC, $[NO_3^-]$ and $[Cl^-]$ were determined in a 1:5 solution (soil/water). The correlative numbers on the X-axis refer to the months that had passed, with cultivation, since the beginning of the trials.

3.3. Relationships between Biochemical Soil Quality Indicators

The values of Pearson's correlation coefficient between biochemical soil quality indicators are shown in Table 6. Significant positive correlations ($p < 0.01$) were found for all soil quality indicators. There was a good correlation between TOC and each of the labile organic carbon fractions, and POC showed the highest value ($r = 0.78$); at the same time, POC showed the best correlation coefficient with LF ($r = 0.81$). WSOC was the labile organic carbon fraction that showed the lowest correlation coefficient with DH and GL ($r = 0.73$ and $r = 0.68$, respectively). There was also a good correlation between the two soil enzymes and all the indicators related to organic carbon, especially between

DH and POC ($r = 0.83$) and LF ($r = 0.85$), with DH having higher correlation coefficients than GL. EC showed a higher correlation coefficient with WSOC ($r = 0.78$) and LF ($r = 0.77$), the $[\text{NO}_3^-]$ of the soil solution also showed a higher correlation coefficient with both labile organic carbon fractions ($r = 0.74$ and $r = 0.71$, respectively) and with DH ($r = 0.66$), and the $[\text{Cl}^-]$ of the soil solution showed the best correlation coefficients with the same indicators, better than the $[\text{NO}_3^-]$ (WSOC: $r = 0.66$; LF: $r = 0.65$; DH: $r = 0.64$).

Table 6. Pearson's correlation coefficients (r) between the different soil quality indicators. TOC: total organic carbon (g kg^{-1} soil); POC: particulate organic carbon (g kg^{-1} soil); LF: light fraction (g kg^{-1} soil); WSOC: water-soluble organic carbon (g kg^{-1} soil); DH: dehydrogenase activity (mg TPF kg^{-1} soil day^{-1}); GL: β -glucosidase activity ($\mu\text{mol PNG kg}^{-1}$ soil h^{-1}); EC: electrical conductivity (dS m^{-1}); $[\text{NO}_3^-]$: concentration of nitrates of the soil solution; $[\text{Cl}^-]$: concentration of chlorides of the soil solution. EC, $[\text{NO}_3^-]$ and $[\text{Cl}^-]$ were determined in a 1:5 solution (soil/water). The p -value was less than or equal to 0.01 ($p < 0.01$) for all coefficients.

	TOC	POC	LF	WSOC	DH	GL	EC	$[\text{NO}_3^-]$	$[\text{Cl}^-]$
TOC	1								
POC	0.78	1							
LF	0.76	0.81	1						
WSOC	0.73	0.68	0.75	1					
DH	0.79	0.83	0.85	0.73	1				
GL	0.77	0.70	0.76	0.68	0.76	1			
EC	0.76	0.61	0.77	0.78	0.71	0.70	1		
$[\text{NO}_3^-]$	0.64	0.62	0.71	0.74	0.66	0.61	0.81	1	
$[\text{Cl}^-]$	0.63	0.54	0.65	0.66	0.64	0.62	0.77	0.87	1

3.4. Measurements of Crop N Status

Plants in CMP had significantly higher values of petiole sap $[\text{NO}_3^-]$ in the three cropping seasons, except at 50 days after transplantation in the first two cropping seasons, than those in CRTMP (Figure 3). The mean values of petiole sap $[\text{NO}_3^-]$ in both management packages, especially in CMP, were above 1500 mg L^{-1} , the maximum sufficiency value established by Peña-Fleitas [67] and Hochmuth [66].

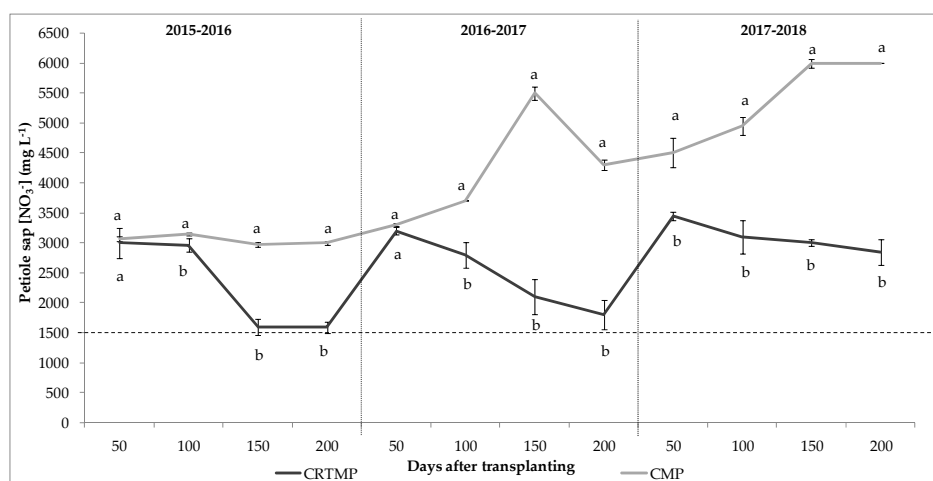


Figure 3. The values of petiole sap $[\text{NO}_3^-]$ measured throughout the three cropping seasons for each of the two management packages. Values are means \pm SE. Different letters indicate significant differences ($p < 0.05$) between the management packages. The vertical dotted lines indicate the beginning of the cropping season. The horizontal dashed line indicates the sufficiency value of petiole sap $[\text{NO}_3^-]$ in the greenhouse sweet pepper crop in Almeria (1500 mg L^{-1}), established by Peña-Fleitas [67].

3.5. Crop Yield

Total production was significantly ($p < 0.05$) higher in the CMP management package in each of the three cropping seasons. The discard was also significantly ($p < 0.05$) higher in CMP, except for in the third cropping season (2017–2018). By contrast, there were no significant ($p < 0.05$) differences in category 1 and 2 production between the management packages, except in the third cropping season, in which both productions were significantly ($p < 0.05$) higher in CMP (Table 7).

Table 7. The mean productions of category 1, category 2, total, and discard in each cropping season in both management packages (CMP and CRTMP) ($n = 4$). Different letters indicate significant differences ($p < 0.05$) between the production values in the same row. Standard deviations are in brackets. Production is expressed in kg m^{-2} (fresh weight).

Production (kg m^{-2})	Crop Season	Management Package	
		CMP	CRTMP
Category 1	2015–2016	5.48 (1.23) a	4.80 (0.95) a
	2016–2017	3.75 (0.66) a	4.30 (0.35) a
	2017–2018	4.60 (0.44) a	3.24 (0.47) b
Category 2	2015–2016	3.18 (1.16) a	2.05 (0.35) a
	2016–2017	4.33 (0.67) a	3.22 (0.45) a
	2017–2018	3.43 (0.38) a	1.91 (0.43) b
Discard	2015–2016	1.60 (0.32) a	0.72 (0.29) b
	2016–2017	1.97 (0.53) a	0.85 (0.29) b
	2017–2018	0.64 (0.28) a	0.61 (0.16) a
Total	2015–2016	10.26 (0.60) a	7.57 (0.62) b
	2016–2017	10.05 (0.93) a	8.34 (0.23) b
	2017–2018	8.66 (0.40) a	5.76 (0.56) b

The seasonal evolution of cumulative category 1, category 2 and total fresh fruit production indicated that significant differences between the packages in the third cropping season occurred almost entirely in the final part of the cropping season, particularly in the last two harvests, when fruit production in the CMP package increased sharply (Figure 4).

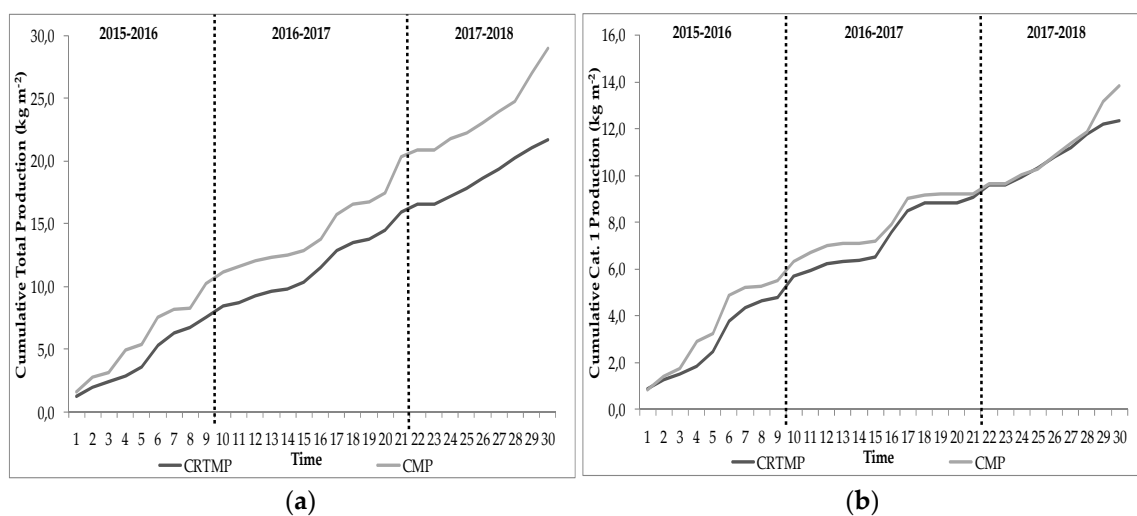


Figure 4. Cont.

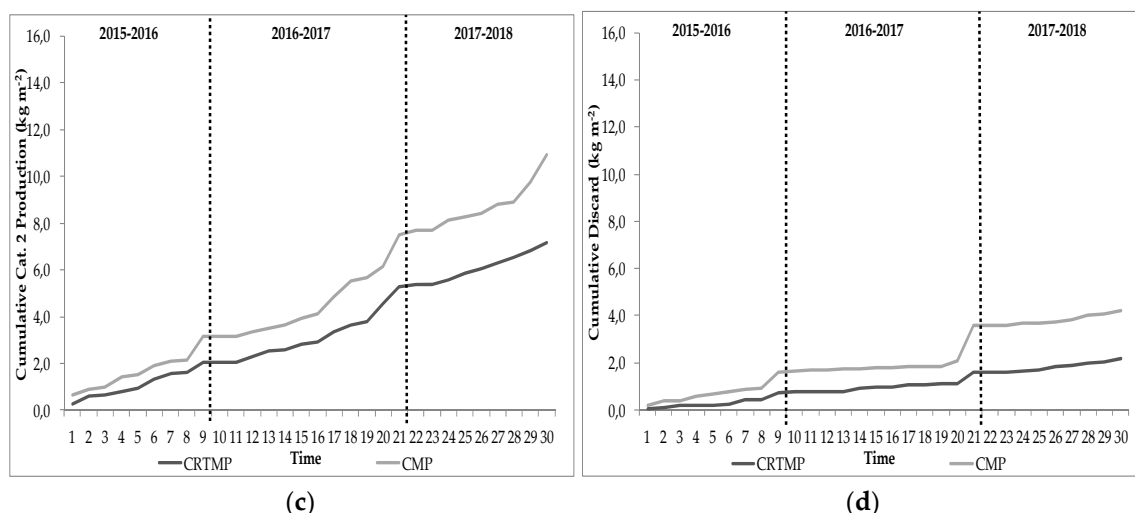


Figure 4. The seasonal evolution of cumulative (a) category 1, (b) category 2 and (c) total fresh fruit production, and (d) discard, in the two management packages (CRTMP and CMP) during the three study cropping seasons (2015–2016, 2016–2017 and 2017–2018).

The percentage of category 1 production in relation to total production was higher in CRTMP in the three cropping seasons, and the percentage of category 1 and 2 (marketable) production was higher in the first two cropping seasons in CRTMP, while in the third cropping season, such relative increases did not occur because of the sharp increase in the final part of the cropping season in CMP (Figure 5).

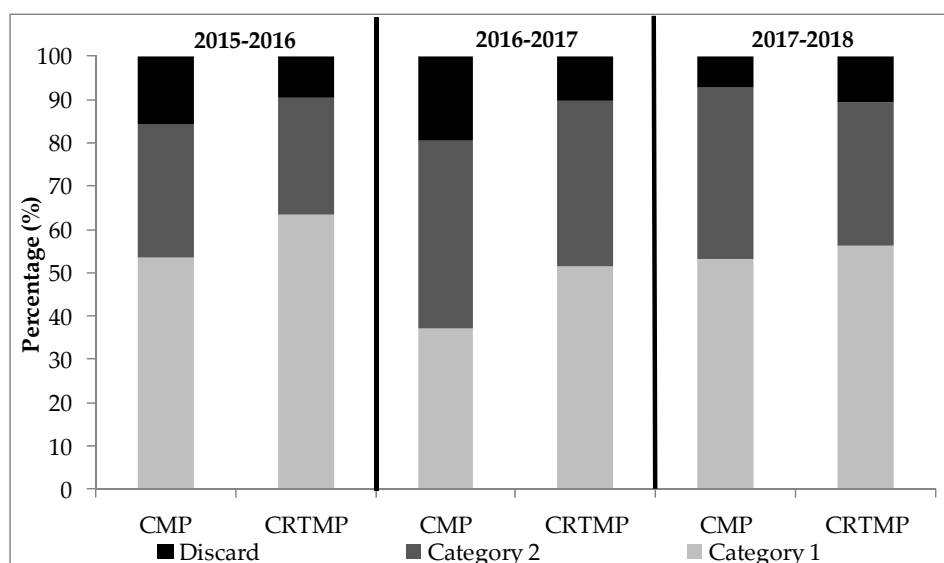


Figure 5. Percentages (%) of category 1 and 2 production and discard, in relation to total production, in the two management packages (CRTMP and CMP) during the three study cropping seasons (2015–2016, 2016–2017 and 2017–2018).

4. Discussion

The application of organic amendments and their incorporation into the soil through tillage increases TOC levels from the first year of cultivation, achieving the desired values in greenhouse soils in the province of Almeria (>15 g kg⁻¹ soil) [68], as is to be expected and as has been noted by numerous authors [69,70]. However, the continuous incorporation of amendments in the different seasons does not contribute to a remarkable differential increase in this indicator, which remains at the same average levels throughout the different seasons. This behavior qualifies it as suitable only for comparisons between different greenhouse management practices, but not for evaluating the

variation in soil quality due to the repeated application of the same management over time. Similar results have been obtained by [71,72]. Tillage distributed carbon labile fractions and improved the conditions for enzyme activity in CRTMP, allowing higher mean values in all soil quality indicators in the 0–15 cm depth range, even from the first cropping season. The higher variability shown in mean values of the biochemical soil quality indicators in CRTMP may be due to changes in the soil's physicochemical properties, soil biota activity, soil composition, and the interaction between them [73,74]. The considerable increases in CRTMP in the labile fractions (POC and LF) serve as an important factor in providing energy to heterotrophic microbial organisms [75,76] and can function as a nucleation site for microbial activity [77], which justifies their significant correlations with soil quality indicators related to enzymatic activity (DH and GL). In this sense, the mean values of DH progressively increase as do the mean values of mineralizable substrates (POC and LF), especially in the second and third cropping seasons. POC and LF, although not equivalent, are closely related, as a part of LF can be part of POC [78], so they are often mistakenly confused [79], which justifies the high correlation coefficient between them. Our results suggest POC as good indicator of soil quality after a short-term change in greenhouse management due to its high sensitivity, and the high and significant correlations with the TOC, enzymatic activities and $[\text{NO}_3^-]$ of the soil solution. The labile fraction increases after organic management are consistent with other studies [26,80], as well as the supply of soil N for crops [81].

Despite the considerable increase in WSOC in CRTMP compared to the initial state, it also increased considerably in CMP, with no significant differences between the management packages in some months, suggesting that it may be affected by factors other than those involved in the management practices used [82]. Some studies support the relationship between WSOC and microbial activity, so that the microbial community can easily use energy sources such as metabolizable organic compounds, extracted as WSOC from the decomposition of the soil organic matter [83,84]; instead, our results show the lowest correlation of WSOC with microbial activity indicators (DH and GL).

In general, an improvement in soil enzyme activity results from increased microbial synthesis due to improved environmental conditions induced by changes in the soil's physicochemical properties [85,86] and could be indicative of the mineralization of organic matter by soil microorganisms [87]. The intracellular activity of the DH enzyme justifies the highest correlation with indicators related to organic carbon [45,88], while GL is present in the processes of cellulose degradation present in plant remains [48,89], suggesting that the DH enzyme is more sensitive to short-term management changes [90]. Authors such as Okur et al. [16] and Zhang et al. [17] have reported that the contribution of organic matter to the soil causes an increase in enzymatic activity, while others [91,92] have reported a decrease in such activity when soils are intensively fertilized with nitrogen, as it was in CMP. These pieces of evidence allow the justification of the differences found between the different management packages tested in this trial. The increases in and correlations between enzyme activity and organic carbon indicators suggest a balanced improvement of soil biological activity, as observed by Yevdokimov et al. [93] and Saikia et al. [94]. These increases are detected from the first cropping season and are maintained throughout the three cropping seasons of study, even in TOC, despite this being an indicator less susceptible, in the short or medium term, to management changes [26,27].

The results of this study showed that the application of CRTMP, in addition to improving soil quality indicators, increased the concentration of nitrates in the soil solution. This could be due, on the one hand, to the direct contribution of soluble nitrogen salts present in the organic amendments but, on the other hand, to the mineralization of the organic matter. The proof for this is the significant correlation between the $[\text{NO}_3^-]$ of soil solution and indicators related to labile organic carbon fractions and enzymatic activity. However, CRTMP, due to the high Cl^- content of the selected organic amendments and the comparatively small amount of drainage, also significantly increased the chloride concentration of the soil solution and the soil electrical conductivity. The $[\text{Cl}^-]$ of the soil solution and soil salinization could have effected the significantly lower total production in CRTMP compared to in CMP; in the third cropping season, moreover, significant differences were detected in the petiole

sap $[\text{NO}_3^-]$ —a sensitive indicator of crop N status in the sweet pepper [95]—in the initial stages between the management packages, contrary to in the two previous cropping seasons, and this could have influenced the significant decrease in marketable and total production. The higher crop yield in CMP can be explained because this practice provides a readily available source of N, which is one of the main factors controlling crop yield [96], in the dripper by fertigation. Padilla et al. [3] also observed differences in crop yields in greenhouses in Almería (Spain) with the incorporation of organic amendments, mainly due to the increase in production at the end of the cropping seasons in CMP. This higher total production in CMP at the end of the cropping season is probably related to the higher differences in petiole sap $[\text{NO}_3^-]$ detected between the management packages after the winter season. The lower values of $[\text{NO}_3^-]$ in the petiole sap in CRTMP may be related to the competition between chlorides and nitrates for uptake from the soil [97,98], thus decreasing nitrate uptake compared to in CMP. Other authors such as Hernández et al. [87] achieved crop yields similar to or even higher than with conventional management in lettuce crops. Although the total production is significantly lower in CRTMP, this form of management is able to increase the fruit quality, which could economically compensate for the difference in total production due to its high value-added nature [26,99], as well as benefit the environment. Other authors observed better results, in terms of quality parameters, in outdoor melon crops with organic management practices compared to with conventional management [100].

Despite the clear improvements that the CRTMP management package induces in the measured biochemical parameters, the high risk of salinization requires a reconsideration of the organic materials used together with the crop residues, as well as the establishment of irrigation schedules that help to minimize this risk [101].

5. Conclusions

Management practices including the tillage and the contribution of crop residues and organic fertilizer in greenhouse soil increase the soil's organic carbon and its labile fractions, thus increasing its enzymatic activity. These improvements in the biochemical indicators of soil quality in the short term occur during three consecutive cropping seasons of sweet pepper in greenhouses and in the first 15 cm of the soil, with considerable improvements from the first cropping season. POC and DH demonstrate, in this cultivation system, their double utility as indicators of soil quality. On the one hand, they will make it possible to establish whether there are differences between different management practices at any given time. On the other hand, they will make it possible to evaluate the effects produced by a change in management over time. In addition to the biochemical indicators, the concentration of nitrates in the soil solution also increases. However, the organic matter used increases the risk of soil salinization in greenhouses, by increasing the concentration of chlorides in the soil solution, and decreases the concentration of nitrates in the petiole sap, which is related to a decrease in total production but an increase in production quality. In this type of management, the optimal management of water and fertilizers is important and advisable to prevent the problem of soil salinization and also to avoid the loss of nutrients provided by organic amendments, especially at the beginning of the cropping season.

In future lines of research, it would be desirable to advance the knowledge about the behavior in greenhouses of different quality indicators—physical, chemical and biological—that allow a composite index of soil quality (SQI) related to the production of these systems to be obtained.

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