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Organic compost effects on *Stevia rebaudiana* weed control and on soil properties in the Mediterranean region

Efeito da aplicação de compostos orgânicos no controlo de infestantes na cultura de *Stevia rebaudiana* e nas propriedades do um solo na região do Mediterrâneo

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S U M M A R Y

Stevia rebaudiana Bertoni is a promising crop for semiarid climates, including Algarve region. The objectives of this work were: to compare the feasibility of the eco-friendly stevia weed control strategy with a compost of vegetable residues (grass clippings and pruning's); to identify the emerged weed species, and to evaluate the effect of compost application on soil properties. Treatments consisted on the application of a 5 cm layer of compost on soil surface or incorporated, and no compost application as control. The trial was set up in six randomized field plots, with four replications. Each plot was divided into three subplots, with one treatment per subplot, in a total of 24 subplots per treatment. Compost application had a distinct effect on weed species. Some species were significantly reduced when compost was applied, namely as mulch. Compost increased soil water content, mainly in area of the trial with lower soil drainage, especially when compost was applied as mulch, as well as other physical and chemical soil properties. Results showed the positive effect of compost on weed control and soil properties during stevia cultivation.

Keywords: mulch, organic farming, water infiltration rate, environment, sustainability, circular economy

R E S U M O

A estévia (*Stevia rebaudiana* Bertoni) é uma cultura promissora para regiões sermiáridas, incluindo o Algarve. Os objetivos deste trabalho foram: avaliar o efeito da aplicação de composto ao solo no controlo das infestantes em estévia; identificar as infestantes que ocorrem em diferentes épocas do ano e avaliar o efeito da aplicação do composto no solo. Utilizou-se um composto comercial, em duas modalidades de aplicação: à superfície (CS) e enterrado a 10 – 15 cm (CI), numa faixa ao longo das linhas da cultura. O controlo foi solo nu (NC). O ensaio foi instalado em seis blocos completos casualizados, com quatro repetições. Cada bloco foi dividido em três parcelas, com uma modalidade por parcela, num total de 24 parcelas por modalidade. O composto afetou de forma significativa as espécies de infestantes identificadas. O composto, sobretudo em cobertura, reduziu significativamente a ocorrência da maioria das espécies. O composto aumentou a retenção de água do solo, em particular na zona onde a taxa de infiltração era menor, e sobretudo quando aplicado em cobertura, mas afetou ainda outras características físicas e químicas do solo. O trabalho evidenciou o efeito positivo do composto no controlo das infestantes e nas características do solo na cultura de estévia.

Palavras-chave: cobertura de solo, produção biológica, taxa de infiltração de água, ambiente, sustantabilidade, economia circular

INTRODUCTION

Stevia (*Stevia rebaudiana* Bertoni) is a South American *Asteraceae*, endemic in Paraguay and the adjacent Brazilian territory. Stevia is cultivated in many regions of the world, including Europe (Ramesh *et al*., 2006) namely in the Mediterranean region (Lavini *et al*., 2008), were the crop can be planted in the field during spring, according to local air average temperature. In this region, stevia behaves as a warm season crop: vegetative growth occurs trough spring and summer, being plant stems harvested along this period. As a short day plant, the first flowers are observed in August, and harvest usually ceases. Full blooming occurs through the end of summer and autumn. Plant canopy is eliminated during winter, due to weather conditions, but most of the plants usually survive and plant regrows from underground parts of the stem. The economic importance of stevia is mainly related to the amount of sweet glycosides, like stevioside, a noncaloric sweetener present in the leaves (Totté *et al*., 2000). Economic and environmental sustainability of this crop might be improved through the application of compost mulching for stevia weed control, while promoting crop yield.

Weeds significantly reduce crop yield and quality (Vasileiadis *et al*., 2012), by competing for water, nutrients, light and space (Navarro *et al*., 2005), and increasing harvest costs (Buhler *et al*., 1998; Ozores-Hampton *et al*., 2001). For these reasons, weed control is of great importance, being often achieved through specific soil mobilization operations (Kienle, 2004), crop rotation, inter-row cultivation, use of a stale-seedbed to kill emerging seedlings before planting or by the use of herbicides (Ozores-Hampton *et al*., 2001; Harrington *et al*., 2011), but none is homologated in the EU, although they have been tested and evaluated (GO4STEVIA, 2018). However, herbicides are not allowed in the EU on organic farming (Regulations EU 834/2007 and 889/2008). Anyway, the use of herbicides can cause environmental problems, affecting man and wildlife (Schneider *et al*., 1988), and the continued use of some herbicides has caused weed shift problems and weed resistance (Zhang, 2003). Public demand for organic products and the relevance of organic farming has increased in recent years, so too has the range of weed control options (Bond and Grundy, 2001). Mulching with organic materials it's an old agricultural technique that can be effective on weed control, has a positive effect on soil nutrient supply, decreases evapotranspiration, reduces erosion, equilibrates soil temperature, improves structure and permeability, nutrient absorption and facilitates the circulation of machinery (Boyle *et al*., 1989; Dick and McCoy, 1993; Labrador, 1996; Lazaroto *et al*., 2008). Compost application generally improves soil physical, chemical and biological characteristics, being one of the few soil conditioners with such a broad effect (Alexander, 1996). Compost improves soil physical characteristics independently of its texture: in fine texture soils, compost avoids compression; in soils with coarse texture it increases the water retention capacity and improves the development of soil aggregates (Boyle *et al*., 1989; Dick and McCoy, 1993; Ozores-Hampton *et al*., 2001). Compost mulching can be an effective technique to suppress weeds (Altieri and Liebman, 1987). Mulching with a layer of 0.10 to 0.15 m of compost is recommended for weed control (FAO, 1987). This control effect may be caused either by the presence of toxic compounds produced during composting (Ozores-Hampton *et al*., 2001) or by reducing light penetration and the radiation of fundamental wavelengths to seedlings development (Ramakrishna *et al*., 2006). However, fine layers of compost, in severe weed infestations, did not provide sufficient weed control (Ozores-Hampton *et al*., 2001). Moreover, detailed information on which weeds species are controlled by compost is scarce.

Knowing that the effect of composts will vary accordingly to its characteristics, the objectives of this work were: i) to evaluate the effect of a 5 cm layer of compost (Nutriverde®, ALGAR S.A., Portugal), produced in windrows from vegetable residues namely grass clippings and gardening prunings. Compost was applied, as mulch or incorporated in the soil, as an eco-friendly weed control in the stevia; ii) to obtain information on the most affected weed species, which is of crucial importance when deciding for this technical option, considering the weed species expected in the field; iii) to evaluate the effect of the type of compost application (as mulch or incorporated) in the soil and on stevia yield.

MATERIAL AND METHODS

Field trial, experimental design and measurements

Experimental field was located in south Portugal (37°02'34.9"N 7°58'15.6"W) at the *Campus* of Gambelas from the University of Algarve, Faro. The trial was installed on a sandy soil, a haplic arenosol (ARh) according to FAO (2006). A pinewood (*Pinus pinea* L.) had occupied the soil for over 30 years, followed by a vegetable cultivation period of two years. During the five years previous to the trial, the soil was left with spontaneous herbaceous vegetation.

In order to improve crop-growing conditions, soil was mobilized before stevia plantation with a ripper, at 0.5 m depth, followed by a rotovator at 0.15 to 0.2 m.

The tested compost was prepared from a mix of gardening pruning's and grass clippings (Nutriverde®, ALGAR S.A., Portugal). This mix was composted in windrow for eight weeks, with mechanical weekly turning, followed by a maturation of a few weeks. Three treatments were tested: application of compost on soil surface as mulch (CS) or incorporated at 0.1 to 0.15 m depth (CI), and no compost application (NC). Stevia was planted in lines separated 0.75 m, with a distance of 0.3 m in the line, corresponding to a density of 44444 plants ha^{-1}. A 5 cm thick layer of compost (34 kg m^{-2}), was applied on a 0.50 m wide stripe along plantation lines of stevia (which were separated 0.75 m) and left on surface or incorporated in the soil. According to plant density, to the width and height of the compost layer, and to compost bulk density, this 5 cm layer of compost represented approximately an application of 200 t ha^{-1}. The trial was set up in six randomized plots (3 m x 0.5 m) with four replications, in a total of 24 plots. Each plot included 9 plants performing a total of 216 plants (24 plots x 9 plants) and was divided into three subplots (0.9 m x 0.5 m), with one sub-plot for each treatment, and three plants per treatment. To avoid side effects from compost application between treatments along the plantation lines, the plants used to determine growth variables were only the middle plants from each treatment in each subplot, performing a total of 24 plants evaluated per treatment.

A drip irrigation system was used for the layout (Netafim, 10 L.h^{-1} drippers). Irrigation water amounts were daily applied, in order to replenish the soil profile to field capacity up to a depth of 0.5 m. To control soil water along the soil profile, soil water content was monitored periodically during the experiment (Reis *et al.*, 2015), gravimetrically measured for a 0.0-0.6 m depth. Immediately after plantation, soil was irrigated at field capacity until 0.5 m depth (Lavini *et al.*, 2008), according to the root system characteristics. During the trial, plants were irrigated two to three times a day, according to the environmental conditions, with a maxim daily irrigation amount of 4.4 mm.day^{-1} corresponding to a maximum irrigation period of 6 minutes, computed according to Allen *et al.* (2005).

All plants were fertilized through foliar spraying with a liquid fertilizer (Ret-Sul, Eibol S.L., Spain).

Weed counting and identification

Weed emergence on each treatment subplot was weekly identified (until species level whenever possible), counted and registered. Weeds were identified and counted in the central zone of each subplot, within an area of 0.45 m^2 per subplot (0.5 m width x 0.9 m long). Weeds were identified and counted during three consecutive periods, according to air temperature evolution; 1st period (temperature decrease, autumn), 2nd period (cold weather, final autumn to winter) and 3rd (temperature increase, final winter and spring).

Soil and compost characterization

Soil samples were analysed before and after the trial to evaluate the effect of treatments. Soil samples were randomly collected in the whole area at the beginning of the trial, before compost application. At the end of the trial, soil samples were collected on the area around 0.1 to 0.2 m from the plants, in each treatment. Compost was analysed for its most relevant characteristics, including phytotoxicity, expressed by the germination index (Zucconi *et al.*, 1985).

Soil and compost pH were measured on a water extract (1:2.5) with a potentiometer (Crison micro pH 2001, Spain). Electrical conductivity of soil (ECs) and compost was read in the previous suspension, after adding 25 mL of distilled water more, with a bench conductivimeter (Crison 522, Spain). Dry matter content (DM) was determined using the method described by Martinez (1992). Organic matter content (Walkley and Black, 1934), potassium (Egner-Riehm method) and phosphorus (Olsen's method) were determined. Sodium was determined by flame photometry (Jenway, PFP7 & PFP7/C, England), after extraction in ammonium acetate.

During the trial, differences were observed on the water infiltration rate during irrigation, according to soil slope, that was around 10%. For this reason, the soil water infiltration rate (WIR) was measured with a Double Ring Infiltrometer (IN2-W, Turf-Tec, EUA), considering three areas on the trial field: higher, medium and lower area, according to the slope. In each area, eight determinations of the infiltration rate were done per treatment (NC, CI and CS), in a total of 96 measurements.

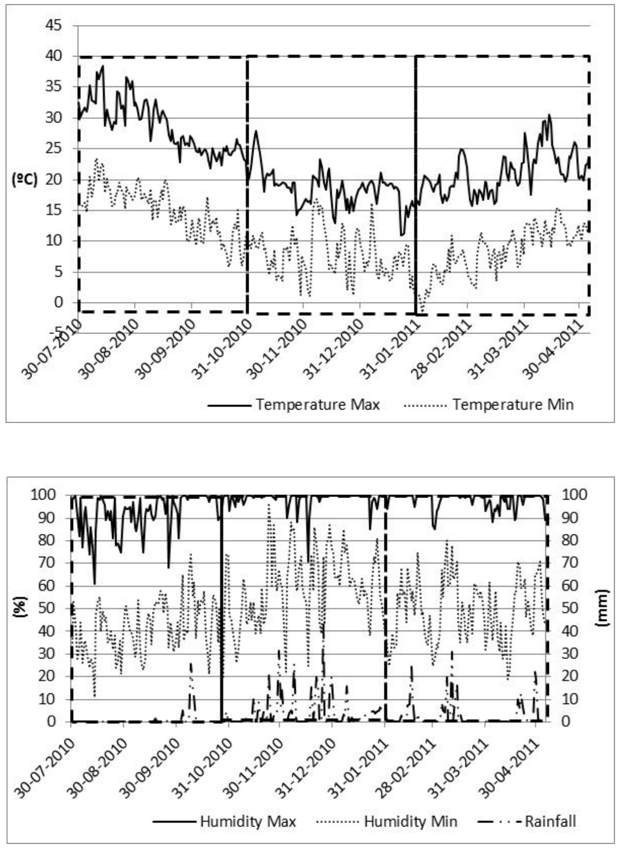

Figure 1 - Temperature (ºC), humidity (%) and rainfall (mm) during the three periods of the trial (separated by the vertical lines on the graphs).

Statistical analyses

Statistical analyses used IBM SPSS Statistics version 20. Soil and weed occurrence data were analysed through one-way Analysis of Variance (ANOVA) and Duncan's Multiple Range Test. Differences were considered significant at $p<0.05$.

RESULTS

Weed control: global aspects

As normal, the occurrence of the different weed species was related to the climatic conditions during each observation period. These three observation periods, based on temperatures evolution: decreasing, stabilized (cold period) and increasing temperature, corresponded to the following dates: 1st period from 31st Jul. - 31st Oct., 2nd period from 1st Nov. - 31st Jan., and 3rd period from 1st Feb. - 6th May, identified on Figure 1.

During the trial, 47 weed species belonging to 20 families were identified (Table 1), distributed by treatments as follows: 46 species from 19 families on soil with no compost (NC); 44 species from 18 families on soil with compost incorporation (CI), and 43 species from 17 families on soil with compost mulch (CS) (Table 2 and 2b). Only nine species emerged during the three observation periods, and 11 species appeared only during one period.

Without compost, the number of weeds was higher than with compost, particularly when it was applied as mulch. Compost significantly reduced the number of plants from 13 species, at least during one of the observation periods.

Whenever compost was used as mulch, four weed species did not occur: *Cardaria draba* L., *Spergularia rubra* L., *Urtica urens* L. and *Reseda luteola* L., while *Silene gallica* L. was observed only in the first observation period (Table 2 and 2b). During the three observation periods, similar

Table 1 - Weed families and species identified during the trial period

Family	Species	Family	Species
Boraginaceae	*Echium plantagineum* L.	Poaceae	*Cynodon dactylon* L.
Brassicaceae	*Cardaria draba* L.		*Poa annua* L.
Caryophyllaceae	*Cerastium glomeratum* Thuill	Fabaceae	*Medicago intertexta* L.
	Spergula arvensis L.		*Medicago lupulina* L.
	Spergularia rubra L.		*Medicago nigra* L.
	Paronychia argentea Lam.		*Medicago orbicularis* L.
Chenopodiacea	*Beta vulgaris* L.		*Melilotus segetalis* (Brot.)
Ciperaceae	*Cyperus rotundus* L.		*Trifolium arvense* L.
Asteraceae	*Arctotheca calendula* L.	Liliaceae	*Muscari neglectum* Ten.
	Calendula arvensis L.	Malvaceae	*Malva sylvestris* L.
	Chamaemelum mixtum L.	Plantaginaceae	*Plantago lagopus* L.
	Chamaemelum fuscatum L.		*Plantago lanceolata* L.
	Conyza bonariensis L.		*Plantago coronopus* L.
	Conyza sp.	Polygonaceae	*Polygonum arviculare* L.
	Lactuca serriola L.	Portulacaceae	*Portulaca oleracea* L.
	Lactuca virosa L.	Primulaceae	*Anagallis arvensis* L.
	Picris echioides L.	Quenopodiaceae	*Chenopodium album* L.
	Sonchus asper L.	Resedaceae	*Reseda luteola* L.
	Sonchus oleraceus L.	Rubiaceae	*Galium aparine* L.
	Senecio vulgaris L.		*Silene gallica* L.
Euphorbiaceae	*Euphorbia peplus* L.	Solanaceae	*Datura stramonium* L.
Poaceae	*Avena sterilis* L.		*Solanum nigrum* L.
	Bromus diadrus Roth.	Urticaceae	*Urtica urens* L.
	Digitaria sanguinalis L.		

behaviors were observed for the species *Plantago lanceolata* L. and *Gallium aparine* L., which always appeared with less abundance on CS (Table 2b). *Conyza bonariensis* L. was not observed in the first observation period, what can be attributed to soil mobilization previous to crop plantation (Wu *et al*., 2007) and the fact of being a positive photoblastic species (Baskin & Baskin, 1998). Later, during the 2nd an 3rd periods, its lightweight seeds would have been wind spread from the surrounding fields and germinated, on the compost or on the soil. This can explain the high occurrence on CS treatment that offered good germination conditions, namely a coarser surface to hold the seeds, and a higher humidity content for seed germination.

First period (summer- autumn)

In the first period of observation, 23 species were identified. Compost, especially when applied as mulch (CS), significantly reduced the number of eight plant species, especially *Portulaca oleracea* L., *Plantago lagopus* L. and *Poa annua* L. (Table 2 and 2b). The species *Solanum nigrum* L., *Poa annua* L. and *Lactuca virosa* L. were not observed on CS. During this first period, *Cardaria dabra* L., *Sonchus asper* L., *Reseda luteola* L., *Lactuca serriola* L. and *Cyperus rotundus* L. were observed only on NC.

Second period (late autumn - winter)

During the 2nd period, with lower temperature than in the first period (average temperature 12 ºC)

Table 2 - Average number of plants[1] from the weed species observed in each treatment (CS, compost mulch; CI, compost incorporated in the soil; NC, no compost)

Species[2]	1st period (31st Jul.–31st Oct.)			2nd period (1st Nov.–31st Jan.)			3rd period (1st Feb.–06th May)		
	CS	CI	NC	CS	CI	NC	CS	CI	NC
Echium plantagineum L.				3a	3a	5a		2a	2a
Cardaria draba L.			1						
Cerastium glomeratum Thuill				3b	18a	3b	10a	34a	28a
Spergula arvensis L.				9b	63a	100a	9b	88a	114a
Spergularia rubra L.								2a	21a
Paronychia argentea Lam.	1a	5a	56a	2a	2a	10b	39a	34a	18a
Beta vulgaris L.				7a	5a	14a	1a	2a	3a
Cyperus rotundus L.			1	28b	133ab	187a	70c	891b	1588a
Arctotheca calendula L.				2b	6ab	14a			
Calendula arvensis L.				6b	19b	48a	7b	8a	15b
Chamaemelum mixtum L.				6b	20b	59a	2a	22a	18a
Chamaemelum fuscatum L.				2a	3a	7a	2b	3b	8a
Conyza bonariensis L.				60a	44a	22b	31a	44a	33a
Conyza sp.				31a	28a	19a	37a	31a	48a
Lactuca serriola L.			1	1b	6a	7a			
Lactuca virosa L.		1a	16a	5a	4a	7a			
Picris echioides L.							2a	5a	8a
Sonchus asper L.			1a	3a	5a	9a		1	
Sonchus oleraceus L.	1a	1a	6a	1a	1a	4a			
Senecio vulgaris L.				6a	7a	9a	1a	2a	2a
Euphorbia peplus L.				14a	33a	42a	3b	16a	16a
Avena sterilis L.				19a	21a	33a			1
Bromus diadrus Roth.				12a	17a	36a			
Digitaria sanguinalis L.	1a	1a	1a						4
Cynodon dactylon L.	7b	7b	16a				2a	3a	2a
Poa annua L.		1b	171a	224c	1055b	2865a	6a	62a	41a

[1] Average number of plants counted in each treatment, on a soil area of 1 m^2. Empty cells indicate that no plants were observed. Number were adjusted to the units (0 when <0.4).
[2] For each species, the average number of plants counted on each treatment, followed by different letter showed statistical differences by Tukey's HSD multiple comparisons post-ANOVA test, at $P \leq 0.05$.

and more rainfall input, the number of observed weed species increased to 35. Compost application continued to show a positive effect on weeds control, by reducing their number, particularly when used as mulch (Table 2 and 2b). Five species were significantly reduced with compost mulch: *Spergula arvensis* L., *Cyperus rotundus* L., *Lactuca serriola* L., *Poa annua* L., *Anagallis arvensis* L.

Third period (late winter - spring)

A similar situation to the 2nd period occurred, being identified 31 weed species where an increase in temperature was observed. Compost reduction effect on weed number was significant when it was applied as mulch, for the species: *Spergula arvensis* L., *Spergularia rubra* L., *Cyperus rotundus* L., *Euphorbia peplus* L., *Trifolium arvense* L., *Plantago lanceolata* L., *Polygonum arviculare* L., *Anagallis arvensis* L., *Chenopodium album* L. (Table 2 and 2b).

Anagallis arvensis L. was present in higher number in the 1st period in CS, but in the 2nd period its number was significantly reduced on CS.

Portulaca oleracea L. was significantly reduced by the compost during the initial warm season. *P. oleracea* L. is one of the world's most aggressive weeds species, ranked in the 8th place of plants with larger distribution in the world (Simopoulos, 2004), with greater abundance in the warmer months (Feng

Table 2b - Average number of plants[1] from the weed species observed in each treatment (CS, compost mulch; CI, compost incorporated in the soil; NC, no compost). (cont.)

Species[2]	1st period (31st Jul. – 31st Oct.)			2nd period (1st Nov. – 31st Jan.)			3rd period (1st Feb. – 06th May)		
	CS	CI	NC	CS	CI	NC	CS	CI	NC
Medicago intertexta L.				3a	6a	2a			
Medicago lupulina L.				3a	6a	3a			
Medicago nigra L.	4a	3a	2a						
Medicago orbicularis L.	26a	15ab	1b	65a	369a	471a	38a	111a	181a
Melilotus segetalis (Brot.)				3a	1a	4a			
Trifolium arvense L.				10a	18a	48a	3b	12a	11a
Muscari neglectum Ten.						1	1		
Malva sylvestris L.	3a	ca	3a			1			
Plantago lagopus L.	64b	93b	618a	15b	33b	198a			
Plantago lanceolata L.	1b	7b	83a	42b	119b	355a	16c	87b	202a
Plantago coronopus L.				2a	1ab	0b	1a	0a	1a
Polygonum arviculare L.						1	1b	4a	4a
Portulaca oleracea L.	12b	60b	469a	5a	27a	32a	11a	8a	9a
Anagallis arvensis L.	47a	1b	5b	78c	369b	694a	36b	118a	98ab
Chenopodium album L.	1b	2ab	3a		2a	1a	1b	4a	3a
Reseda luteola L.			1						
Galium aparine L.	3b	2b	106a	48b	181ab	305a	21b	125ab	182a
Silene gallica L.	6a	1a	6a						
Datura stramonium L.	2a	2a	4a	1a	1a	1a	1		
Solanum nigrum L.		4a	6a	1a	1a				
Urtica urens L.					1				

[1] Average number of plants counted in each treatment, on a soil area of 1 m^2. Empty cells indicate that no plants were observed.
[2] For each species, the average number of plants counted on each treatment, followed by different letter showed statistical differences by Tukey's HSD multiple comparisons post-ANOVA test, at $P \leq 0.05$.

et al., 2015) in sites with enough water availability in the soil (Yazidi *et al.*, 2007).

Compost mulch did not prevent the C_4 perennial summer weed *Cyperus rotundus* L. emergence but it was dramatically reduced during the 3rd period: 20 times less plants emerged on compost mulch than on soil with no compost (Table 2). According to the level of *Cyperus rotundus* L. presence in the soil, control measures previous to crop installation might be required (GO4STEVIA, 2018). *Spergula arvensis* (present in the 2nd and 3rd periods), *Plantago lagopus* L. (present in 1st and 2nd periods) and *Poa annua* and *P. lanceolata* (present in the three periods) had higher plant densities on NC treatment.

Compost effect on soil properties

Before the trial, soil presented an almost neutral pH, low salinity and low or undetectable concentrations of heavy metals (Table 3). Compost presented a pH of 8.5, an electrical conductivity of 1.8 $dS.m^{-1}$, 33% (w/w) of organic matter and a germination index of 67.8 %, above the lower limit (65%) to be considered adequate for agricultural utilization according to Zucconi *et al.* (1985).

After the trial, soil pH increased from 7.3 to 8.2 or 8.4 when compost was incorporated in the soil or used as mulch, respectively (Table 3). ECs slightly increased from 0.06 $dS.m^{-1}$ to 0.07 $dS\ m^{-1}$ in CI, and to 0.08 $dS\ m^{-1}$ in CS. Organic matter, potassium, phosphorus and sodium contents were higher in both treatments with compost. At the end of the trial, soil moisture was higher were compost had been applied (Table 3).

Visual field observations during trial irrigation, regarding the different water infiltration rate, were confirmed by the determination of WIR *in situ*. In the highest and the middle areas of the field no differences on WIR were observed between treatments, but in the lower area a much

Table 3 - Main properties[1] of the soil before the trial, the compost and the soil after the trial, from each treatment (CS, CI and NC)

Variable[1]	Soil		Compost	Treatments[2]		
		remarks		CS	CI	NC
Texture	sandy	coarse or fine				
Organic matter (%)	1.36	low	33	7.8a	5.4a	0.9b
Ashes (%)	98.64		67			
Dry matter (%)	94.7		71	80.5b	79.9b	89.2a
pH	7.31	neutral	8.65	8.41a	8.15b	7.73c
CE_s ($dS.m^{-1}$)	0.058	no saline effect	1.792	0.08a	0.07a	0.02b
$CaCO_3$ active (%)	0 – 6					
$CaCO_3$ total (%)	1 – 5					
N total (%)	0.62		1			
$N\text{-}NH_4^+$ (ppm)	43.29					
$N\text{-}NO_3^-$ (ppm)	181.3					
K_2O (%)	0.011	high	0.825	0.045a	0.033ab	0.014b
P_2O_5 (%)	0.023	high	0.6	0.801a	0.149b	0.153b
Ca (%)	0.051		5.25			
Mg (%)	-		0.57			
Na (%)	-	-	-	0.006a	0.002ab	0.001b
Mn ($mg.kg^{-1}$)	4.310	very low				
Zn ($mg.kg^{-1}$)	0.089	very low				
Cu ($mg.kg^{-1}$)	0.533	low	18.6			
Cr ($mg.kg^{-1}$)	0		17.5			
Ni ($mg.kg^{-1}$)	0		12.5			
Zn ($mg.kg^{-1}$)	-		67.5			
Cd ($mg.kg^{-1}$)	-		0.15			
Germination index (%)	-		67.8			

[1]ECs, soil electrical conductivity
[2] Treatments: CS, compost on surface, as mulch; CI, compost incorporated at 0.1 to 0.15 m depth and NC, no compost application.
[2] Compost treatments: CS, compost mulch; CI, compost incorporated in the soil; NC, no compost. On each column, values followed by the same letter do not differ at $P \leq 0.05$ (Duncan's test).

lower infiltration rate occurred on NC treatment (Table 4).

Compost improved soil properties, as indicated by the water infiltration rate determinations, thus contributing to superficial water erosion reduction and increasing soil water retention (as indicated by the previously mentioned higher moisture content of soil with compost). In this study, the application of only a 5 cm layer of compost, especially as mulch, was enough to improve water infiltration.

The middle area of the trial exhibited the highest infiltration rate for all the treatments. Water infiltration rate was somewhat lower on the higher area, and dramatically reduced on the lower area, except where compost was applied as mulch (Table 4). In the lower area (with the lowest WIR), compost strongly increased WIR, especially when applied as mulch. Compost increased the WIR to a similar level to the observed in the other two areas of the trial field (middle and higher). In the lower area of the field, where WIR was lower, its value more than doubled with compost mulching (CS), when compared to compost incorporation in the soil (CI) (Table 4).

Table 4 - Infiltration rate ($mL.min^{-1}$) measured in the different areas of the field trial, according to field slope

Compost treatment[1]	Higher area	Middle area	Lower area
CS	62.3aA	86.3aA	62.0aA
CI	75.3aA	82.5aA	26.5bAB
NC	42.8bA	77.8aA	6.75cB

[1] Compost treatments: CS, compost mulch; CI, compost incorporated in the soil; NC, no compost (Duncan's test). On each column, values followed by the same upper letter do not differ at $P \leq 0.05$. On each line values followed by the same lower letter do not differ at $P \leq 0.05$ (Duncan's test).

Stevia rebaudiana Bertoni yield

Globally, compost increased plant growth and yield (Table 5). The dry weight ratios of leaves, stems and flowers were significantly higher on CS and CI and large yield differences due to the application of compost were determined.

Table 5 - *Stevia rebaudiana* Bertoni yield

Variable[2]	Treatments[1]		
	CS	CI	NC
Total dry weight (kg ha^{-1})	571a	548a	187b
Leaves dry weight (kg ha^{-1})	194.3a	187.5a	71.6b
Stems dry weight (kg ha^{-1})	174.7a	141.4a	45.0b
Flowers dry weight ((kg ha^{-1})	209.2a	212.2a	70.6b
Leaves and stems dry weight ratio	1.82a	1.90a	3.55a

[1] CS, compost on surface (mulch); CI, compost incorporated in the soil and NC, without compost.
[2] On each line, the values followed by the same letter do not differ for $p \leq 0{,}05$ (Duncan's test).

DISCUSSION

Weed control

Globally, the highest number of weeds was observed when no compost was applied to the soil, and the lowest number with compost mulch, as previously reported (Ozores-Hampton *et al.*, 2001; Brown and Tworkoski, 2004; Ramakrishna *et al.*, 2006). Moreover, compost reduced weed diversity, both on families and species, as reported by Ramakrishna *et al.* (2006), namely on weeds from the Resedaceae family.

Considering that the compost was mature, as indicated by Zucconi's test and by the fact that it improved stevia early growth, the reduction on weed emergence can not be attributed to the presence of phytotoxic compounds (Roe *et al.*, 1993), unless these compounds were present in such an amount and quality that they were able to reduce seed germination (on Zucconi's phytotoxicity test) but not stevia early growth. Other compost characteristics might have influenced soil conditions for weed emergence (Ramakrishna *et al.*, 2006). Compost mulch is favourable to the biological control of most weeds, since it inhibits plant emergence by preventing light penetration and/ or excluding certain light wavelengths that are needed for the growth of weed seedlings (Baskin and Baskin, 1989; Ossom *et al.*, 2001). Usually, weed germination inhibition increases with soil depth (Ozores-Hampton, 1998). When compost was applied as mulch, even only at a 5 cm height layer, it could have inhibited the emergence of some weed seeds. Braga *et al.* (2010) suggested that seeds may lose viability or be induced to dormancy due to soil mobilization, what could have occurred on CI treatments. Ebrahimi and Eslami (2011) found that compost incorporation in the soil might place some seeds at 10 to 15 cm depth, preventing germination. Also, in both treatments with compost, the relatively high compost pH (8.5) and electrical conductivity (1.8 $dS.m^{-1}$) might have inhibited the germination of some weed species, especially when it was used as mulch.

By the end of the trial, a lower number of weed species had emerged where compost was applied, showing that a degree of weed control by compost application had been achieved.

Mulching with a 5 cm layer of compost may provide an environmentally friendly option of weed control, decreasing chemical control need, and contributing to soil fertilization by reducing the need for synthetic fertilizers. The use of composts from organic residues increases circular economy in agriculture, favours agriculture sustainability and contributes to a safer environment and public health.

Soil properties

Compost application increased soil electrical conductivity (ECs) and pH (Table 3). It is known that the application of compost to the soil might change its pH: neutral or alkaline compost applied to a soil with a lower pH will increase its pH if the quantities are appropriate. The concentration of soluble salts might also be increased by compost application, thus increasing its ECs (Alexander, 2005).

The application of compost significantly increased soil organic matter content (Table 3) as reported by Labrador (1996). Compost also improved soil fertility (Dick and McCoy, 1993; Jakobsen, 1995;

Alexander, 2005), by increasing the nutrients available to the plants, namely P and K (Barker, 2005). In this study, the raise in organic matter content favoured P and K increase only on CS treatment (Table 3).

The WIR increase (Table 4) agrees to previous reports stating that, when applied in sufficient quantity, the addition of compost has both an immediate and a long-term positive impact on soil structure (Alexander, 1996), preventing soil compaction, improving the formation of soil aggregates (Boyle *et al.*, 1989), and increasing soil water retention capacity (Boyle *et al.*, 1989; Alexander, 1996; Torres *et al.*, 2003). This effect was clearer when compost was used as mulch: no significant differences on WIR among the three areas of the trial field under this treatment (Table 4).

These results showed that there were differences in the initial soil physical properties (indicated by WIR) but - with the application of compost, namely as mulch - it was possible to overcome the worst soil physical conditions. When compost was incorporated in the soil, a significant increase of the infiltration rate in the lower area occurred, and an even stronger reduction with no compost application.

From agronomic and economic standpoints, the application of a 5 cm layer of compost on soil surface (mulching) created more favourable conditions than its incorporation in the soil, as indicated by the increased water infiltration rate and the reduced weed emergence.

Stevia yield

The application of compost increased the organic matter and nutrient content in the soil, with a positive effect in the stevia yield, which had been observed in other crops (Reis *et al.*, 2015, 2017). Stevia has low nutrient requirements, being adapted to poor quality soils (Ramesh *et al.*, 2006), however, a nutrient deficiency can be prejudicial (Utumi *et al.*, 1999). Stevia increased yield with compost mulch, relatively to its incorporation in the soil, might be attributed to the greater nutrient availability around the upper roots, at a few cm depth, than in the soil at 15 cm depth. In fact, it is known that stevia root system is hardly ramified and does not deepen, distributing itself near the soil surface (Zaidan *et al.*, 1980). The increase in productivity due to compost application contributes to the reduction of chemical fertilizers, increasing stevia production sustainability.

CONCLUSIONS

Under the trial field conditions, the application of a 5 cm layer of compost reduced the number of weeds, particularly when it was used as mulch. Compost prevented the emergence of some weed species and significantly reduced others. Detailed information is provided on what species are controlled, and up to what extent. It was shown that some degree of weed control with compost (Nutriverde®) is possible, but it will vary with the local weed species and environmental conditions. Compost application to the soil may reduce or eliminate the use of herbicides, safeguarding public health and the environment.

The application of compost increased the water content in the soil, organic matter, electrical conductivity, pH, P, K, Na and improved physical properties, especially when applied as mulch, resulting in a stevia yield increase.

From agronomic and economic standpoints, compost application as mulch was more favourable than its incorporation in the soil. Compost mulch increased yield and reduced weeds, that associated to the lower application costs of compost as mulch, suggests that compost mulch is an interesting cultural option for stevia production.

Compost mulching, by reducing weeds and chemical fertilization needs, contributes to increase of sustainability of agriculture and the objective of a circular economy in society.

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