Use of organic amendments in table grape: effect on plant root system and soil quality indicators

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Abstract

The application of different organic matter sources as soil amendments is a common practice to stimulate root development and soil quality to improve crop yield and quality. For evaluating the effect of organic amendments on soil quality indicators and agronomic variables in table grape (*Vitis vitifera*) var Thompson seedless, different treatments including compost from grape pomace, humic extract, microbial inoculant, and chemical NPK fertilization, were evaluated in a pot experiment using an Inceptisol soil. Organic materials were applied in four C rates: compost, 0, 125, 250 y 500 g C pot⁻¹; humic extract, 0, 25, 50 and 100 g C pot⁻¹; compost and humic extract at their maximum C rates were also evaluated in absence of chemical fertilization, and microbial inoculant as bio-stimulant. Results showed a stronger root development in plants with compost and inoculant application. Furthermore, organic matter mineralization increased nutrient availability; this was evidenced by an increment of enzymatic activities, particularly β -glucosidase, acid phosphatase, and alkaline phosphatase, in all treatments receiving compost. On the other hand, the application of humic extract produced a larger increment in WSC per carbon unit applied compared to compost, meaning that the former would be more efficient than the latter to provide C for soil microorganisms. This study showed that the joint application of compost, mineral fertilizer, and microbial inoculant should be considered to improve root development in Table grape (*Vitis vinifera* L.) and soil quality, under Integrated Nutrient Management (INM) programs.

Keywords: Compost, humic substances, root density, enzymatic activity, soil quality indicators

1. Introduction

The root system plays an important role on physiological and biochemical development of plants due to its influence on nutrient and water uptake, exploratory capacity, and anchorage into soil (Páez- García *et al.*,

2015). Therefore, a good root development is the key to achieve high yield and quality in table grape (*Vitis vinifera* L.) (Palma, 2006; Tomasi, 2016). Root growth pattern depends on age, variety, rootstock,

nutritional status, climate, and environmental stresses (Callejas *et al.*, 2009; Ruiz-Herrera *et al.*, 2015). Smaller roots (2-6 mm in diameter) can emerge and grow both horizontally or vertically. The smaller roots are extended in a few extensions, which are generally thin (1-2 mm in diameter) with fast growth, but they die some weeks after emergence, and are replaced continuously (Terence *et al.*, 2002). The root distribution of table grape in soils is influenced by diverse factors as temperature, texture, water, nutrient availability, pH, organic matter content and tillage (Palma, 2006; Tomasi, 2016).

Table grapes are cultivated in arid and semi-arid regions under irrigated soils, where many times the plants are exposed to salinity and water stress. Orchards are commonly fertilized with NPK and micronutrients sources (Sierra, 2001). Nevertheless, soil agronomic management has been focused on organic matter to improve soil organic carbon (SOC), chemical-physical conditions, and water content in the root zone (Fincheira-Robles *et al.*, 2016; Gaiotti *et al.*, 2016). Commercial products based on humic and fulvic acids are available. The chemical extraction of humic and fulvic acids lead to the formation of three fractions: humic acids, fulvic acids and humins (Ortega and Fernández, 2007). The humic substances influence soil fertility through the improvement of soil structure, the increase chelating minerals and its degradation (Anderson and Schoenau, 1993; Scotti *et al.*, 2015; Nardi *et al.*, 2016). Furthermore, compost has been reported for its ability to reduce soil erosion and improve soil fertility and structure. Compost could improve structure, porosity, plant nutrients, enzymatic activities and the diversity of fungal and bacterial species with ability to stimulate plant growth (Martínez *et al.*, 2010). Recently, Martínez *et al.* (2016) reported that compost quality depends heavily on chemical composition and sanitary parameters, where hydrolytic enzyme activities,

total bacteria count and humic acid: fulvic acid ratios were the parameters of greater sensitivity. Additionally, microbial inoculants represent an alternative to formulate bioproducts containing living microorganisms or their metabolites in organic or inorganic substrates to promote plant growth (Vejan *et al.*, 2016). The microbial pathways promote growth through the following mechanisms: nitrogen fixation, phosphate solubilization, iron uptake, phytohormones level modulation, excretion of antibiotic, enzymes and siderophores (Martínez-Viveros *et al.*, 2010).

The application of carbon, as compost or humic extracts, and microbial inoculant can affect soil quality by improving physical, chemical, biochemical and microbiological soil properties, stimulating root development and plant. The objectives of this research were: 1) to determine the effect of two organic matter sources and a microbial inoculant on selected chemical and biological soil properties, and root and shoot development in table grape, variety Thompson seedless at establishment and 2) to relate soil properties and plant growth to determine the most sensitive soil quality indices explaining root and shoot development.

2. Materials and Methods

2.1. Experimental design and plant material

A pot experiment, under field conditions, was conducted in Limarí Valley (29°54'28"S, 71°15'15"W) located in Coquimbo Region (Chile). This zone is one of the important table grape producing areas in Chile, with a Mediterranean climate and annual average rainfall of 100 mm. The plant material utilized was Table grape *Vitis vinifera* L. var Thompson seedless (one-year-old) cultivated on their own roots, and planted on 20 L pots using an Inceptisol soil. Eighteen treatments and 6 replications were used and were dis-

tributed in a complete randomized design (Table 1). Evaluated rates of compost were: 500, 1000 and 2000 g of product pot⁻¹ equivalent to 125, 250, and 500 g C pot⁻¹, respectively, while rates of humic extract were: 1000, 2000 and 4000 mL pot⁻¹ equivalent to 25, 50 and 100 g C pot⁻¹, respectively. Both C sources were evaluated in the presence or absence of microbial inoculant. Furthermore, the maximum rates of amendments were evaluated with and without of mineral fertilizer application. Two controls were used: chemical

fertilization and an absolute control without any application. Compost was added once at the beginning of the experiment and humic extract was applied in ten split applications during the season. Furthermore, microbial inoculant was added twice, while a fertilizer solution was applied in six equal splits during the season. The cultural practices, including irrigation and manual weed control, were the same for all treatments. The evaluation period corresponded to one growing season (September to May).

Table 1. Applied treatments

Treatment	C source	Chemical fertilization ¹	Compost (g pot ⁻¹) ²	Humic Extract (L pot ⁻¹) ³	Microbial inoculant (mL pot ⁻¹) ⁴	C rate (g pot ⁻¹)
T ₁	Compost	Yes	500			125
T ₂	Compost	Yes	1000			250
T ₃	Compost	Yes	2000			500
T ₄	Compost	No	2000			500
T ₅	Compost	Yes	500		400	500
T ₆	Compost	Yes	1000		400	500
T ₇	Compost	Yes	2000		400	500
T ₈	Compost	No	2000		400	500
T ₉	Humic extract	Yes		10		25
T ₁₀	Humic extract	Yes		20		50
T ₁₁	Humic extract	Yes		40		100
T ₁₂	Humic extract	No		40		100
T ₁₃	Humic extract	Yes		10	400	25
T ₁₄	Humic extract	Yes		20	400	50
T ₁₅	Humic extract	Yes		40	400	100
T ₁₆	Humic extract	No		40	400	100
T ₁₇	None	Yes				0
T ₁₈	None	No				0

¹Chemical fertilization: Novatec Solub 21®, (stabilized ammonium with nitrification inhibitor 3,4 DMPP): 20 g pot⁻¹, phosphoric acid 15 mL pot⁻¹ and potassium sulfate 10 g pot⁻¹. ²Application only at the beginning. ³Four applications 1, 4, 5, 6. ⁴Two applications, one at 1st week and other at week 6th.

2.2. Amendment substrates and microbial inoculant

Compost was obtained from an optimized co-composting process of grape pomace and goat manure and characterized according to the Chilean standard, NCh 2880/16 (INN, 2016). Humic extract was produced from the same compost, extracted during 18 hours

using 0.3 M KOH and a ratio extractant: compost of 10:1. Humic extract was added in dilution 1:100 in water in order to prevent physicochemical instability and the damage to plant by EC (Ortega and Fernandez, 2007). Mineral fertilizer solution was made based on 25 g N pot⁻¹, 9 g P₂O₅ pot⁻¹ and 30 g K₂O pot⁻¹, which are provided by Novatec Solub 21®, H₃PO₄ and K₂SO₄

(50% K₂O), respectively. The microbial inoculant consisted of a mixture of enzyme-producing rhizobacteria that included: *Pseudomonas* sp., *Ochrobactrum anthropi*, *Brevundimonas* sp., and *Sphingomonas paucimobilis*. The bacterial strains were isolated from compost derived from grape pomace and goat manure, with bio-stimulant action and formulated in a concentration of 6.2×10^{10} CFU mL⁻¹. Microbial inoculant solution was applied at the rate of 200 mL pot⁻¹, twice during the season, in the corresponding treatments (see Table 1).

2.3. Soil sampling

Soil samples from each pot were collected at 20 cm depth at the end of the experiment. The samples were transported immediately to the laboratory to determine chemical, biochemical and microbiological properties.

2.4. Measured variables

Initially, the organic amendments were characterized according to the variables established by Chilean Standard NCh 2880-2016 (INN, 2016) and those proposed by Test Methods for Examination of Compost and Composting (Thompson *et al.*, 2001). Soil samples were analyzed according to the methods of Sadzawka *et al.* (2004). Humic and fulvic acids contents (HA+FA) were determined by Anderson and Schoenau (1993), modified for compost.

Microbial populations were determined by the plate count method for isolating heterotrophic bacteria (nutritive agar), fungi (PDA agar), yeasts (YPG agar), actinomycetes (oat agar) and phosphate solubilizer microorganisms (PSB) (SMRS1 agar) (Martínez and Gutiérrez, 2010). The enzymatic activities were determined following the methods recommended by Dick *et al.* (1996), including β -glucosidase potential activity (*p*-nitrophenol method) and acid and alkaline phosphatase potential activities (*p*-nitrophenol method); urease

activity was determined by Kandeler *et al.* (1999), using the indophenol blue technique (García *et al.*, 2003).

2.5. Evaluation of agronomical variables

Trunk diameter (TD) and plant height were measurement after 0, 8, and 13 months from plantation. The diameter was measured with a caliper and the shoot cross sectional area (SCSA) was calculated as plant vigor indicator. In addition, at the final evaluation time, roots of each treatment were collected to determine root dry matter (DM) by washing the soil from each pot and oven desiccation at 70 °C, until constant weight. Results were expressed as density units dividing the root dry mass by the volume of soil.

2.6. Statistical analysis

Data were analyzed using SAS statistical software (SAS, 2008). Data evaluation included analysis of variance (ANOVA) with protected LSD test ($p < 0.05$), and correlation analysis.

3. Results

3.1. Quality of the organic amendments and base soil substrate

The compost used for the experiment showed physical, chemical, biochemical, and toxicological characteristics that allowed its classification as mature compost (Martínez *et al.*, 2016) type A (INN, 2016). On the other hand, humic extract presented lower C content, but similar pH and EC values compared with commercial humic extracts from leonardite (Ortega and Fernandez, 2007). The base soil showed low organic matter content, a property typically associated with Inceptisols soils present in semi-arid regions (Table 2).

Table 2. Chemical and biochemical characteristics of soil, compost and humic extract used for the experiment.

Variable	Unit	Base Soil	Compost	Humic extract
Acid Phosphatase (UP)	$\mu\text{g p-nitrophenol g}^{-1}\text{h}^{-1}$	203	849	3
Alkaline Phosphatase (UP)	$\mu\text{g p-nitrophenol g}^{-1}\text{h}^{-1}$	185	1338	33
B-glucosidase (UBG)	$\mu\text{g p-nitrophenol g}^{-1}\text{h}^{-1}$	78	238	ND
Urease (UU)	$\mu\text{g NH}_4 \text{g}^{-1}\text{h}^{-1}$	84	221	14
Humic acids	%	0.54	5	2.34
pH		8.1	8.6	12.2
EC	dS m^{-1}	0.7	0.88	29.6
N-NH ₄	mg kg^{-1}	8.0	72	49
N-NO ₃	mg kg^{-1}	5.0	309	43
P- Olsen	mg kg^{-1}	7.0	55.6	-
Organic Matter	%	1.4	44.5	0.80
Organic C	%	1.5	24.7	0.25
Total N	%	0.1	1.8	0.04
C/N ratio		11.2	13.4	6.25

3.2. Effect of organic amendments application on soil properties

Chemical properties, pH and EC, showed significant differences among treatments ($p < 0.05$). As expected, treatments with humic extract had higher pH and EC values compared with compost. However, at the end of the experiment the maximum EC values were slightly lower than the control with no organic amendments. The observed increase of EC values at the beginning of the experiment due to humic extract

application triggered a significant reduction on microbial activity and plant growth, which could not be recovered during the season. Therefore, soil had to be leached to reduce EC. For this reason, only chemical properties were evaluated in treatments containing humic extract. Soil content of humic and fulvic acids was higher in all treatments receiving organic matter in comparison to the control, particularly when the maximum level of C was added ($p < 0.05$). The NO₃-N levels were higher in compost treatments ($p < 0.05$) (Table 3).

Table 3. Effect of the applied treatments on selected soil chemical properties

T	Olsen-P	N-NH ₄	N-NO ₃	Avail. N	HFa	OM	WSC	pH	EC
	mg kg ⁻¹				%		mg kg ⁻¹		dS/m
T ₁	24.99±4.99	4.33±0.08	2.43±0.37	6.76±4.15	0.28±0.1	0.69±0.08	15.9±1.2	7.02±0.7	0.16±0.13
T ₂	33.02±13.22	2.47±1.34	3.06±1.09	5.54±2.35	0.65±0.22	1.6±0.38	21.5±6.69	7.28±0.06	0.13±0.039
T ₃	22.59±2.43	5.17±0.8	2.2±1.64	7.37±0.88	1.31±0.48	2.61±0.75	25.0±6.25	7.23±0.42	0.12±0.039
T ₄	25.66±4.78	1.69±0.84	2.16±1.25	3.86±0.9	1.65±0.38	3.04±1.25	22.2±4.3	7.86±0.83	0.17±0.04
T ₅	24.16±9.65	9.08±9.57	3.16±2.26	12.25±10.96	0.43±0.12	0.93±0.22	15.9±1.2	7.20±0.35	0.22±0.12
T ₆	28.19±11.4	8.88±10.7	3.33±1.25	12.21±10.96	0.99±0.29	1.47±0.74	18.7±2.08	6.95±0.16	0.21±0.1
T ₇	26.54±10.6	2.9±0.78	3.1±0.81	6.01±1.6	1.61±0.33	2.49±0.52	27.08±4.17	7.02±0.27	0.14±0.046
T ₈	18.79±8.32	6.71±5.6	3.06±1.68	9.77±7.02	2.29±0.90	3.20±0.51	28.5±5.24	7.21±0.35	0.16±0.06
T ₉	15.36±5.83	1.09±1.04	1.06±0.46	2.16±0.99	0.33±0.06	0.52±0.06	12.5±2.08	8.18±0.13	0.18±0.04
T ₁₀	16.95±7.47	2.68±1.6	1.56±0.46	4.24±2.01	0.42±0.05	0.60±0.1	14.5±5.58	8.63±0.43	0.22±0.1
T ₁₁	24.3±22.6	0.63±0.58	1.9±1.17	2.56±1.66	0.40±0.13	0.60±0.06	16.67±2.08	8.81±0.47	0.31±0.13
T ₁₂	12.0±7.0	1.16±1.49	1.83±0.61	2.99±1.50	0.44±0.12	0.61±0.05	15.97±5.21	8.9±0.08	0.23±0.01
T ₁₃	14.6±7.0	2.8±2.91	1.13±0.5	3.93±3.07	0.36±0.11	0.66±0.15	12.5±2.08	8.09±0.01	0.22±0.02
T ₁₄	24.2±19.6	1.12±0.74	0.93±0.32	2.05±0.97	0.35±0.07	0.64±0.17	11.1±5.24	8.4±0.11	0.18±0.01
T ₁₅	26.11±2.23	2.71±1.53	1.46±0.43	4.19±1.66	0.41±0.17	0.5±0.04	18.06±4.34	8.94±0.54	0.34±0.2
T ₁₆	11.83±5.77	1.55±1.26	0.6±0.33	2.15±0.91	0.43±0.19	0.66±0.17	17.36±3.18	9.01±0.47	0.52±0.02
T ₁₇	11.12±2.68	3.23±1.57	0.66±0.35	3.89±1.81	0.23±0.17	0.67±0.1	13.19±3.42	7.45±0.52	0.17±0.08
T ₁₈	15.7±2.7	1.72±1.43	1.23±0.85	2.95±2.28	0.35±0.13	0.56±0.12	12.5±3.8	7.58±0.56	0.17±0.09
LSD ² _{TR}	ns	ns	1.73	ns	0.50	0.74	6.67	0.91	0.19
LSD ³ _{OM}	5.80	2.76	0.59	2.58	0.31	0.44	2.95	0.32	0.076
LSD ⁴ _{IN}	ns	ns	ns	ns	ns	ns	ns	ns	ns

¹Variation is expressed as standard deviation. T: Treatment; HFa: humic and fulvic acids; OM: organic matter; WSC: water-soluble carbon; EC: electrical conductivity. ²Least significant difference; ³Compares compost vs humic extract; ⁴compares inoculated vs non inoculated ns: not significant ($p > 0.05$)

Soil organic matter (SOM) showed an increase with C rate in treatments with compost. In contrast, humic extract did not produce any change on total SOM (Figure 1a,b). However, the water soluble carbon (WSC) increased in both organic amendments according to C rate (Figure 2). Interestingly, the

slope of WSC increase with C rate was larger for humic extract ($0.048 \text{ mg kg}^{-1} \text{ g C}^{-1}$, Figure 2b) than compost ($0.0257 \text{ mg kg}^{-1} \text{ g C}^{-1}$, Figure 2a). Thus, humic extract would be more efficient than compost to provide C for soil microorganisms, particularly soluble C.

Figure 1. Variation of Soil Organic Matter (SOM) as function of C rate applied as: A) Compost and B) Humic extract.

Figure 2. Variation of Water Soluble Carbon (WSC) as function of C rate applied as: A) Compost and B) Humic extract.

3.2.1. Effect of Compost application on Biochemical Properties

Biochemical analysis revealed that all compost treatments increased potential activity of β -glucosidase and acid phosphatase enzymes,

compared to the control ($p < 0.05$). On the other hand, high rates of C provided by compost and humic extract decreased urease potential activity ($p < 0.05$). Finally, the presence of microbial inoculant increased β -glucosidase potential activity while urease one was decreased (Table 4).

Table 4. Effect of compost applications on soil enzymatic activities¹

T	β-Glucosidase (UBG)	Acid phosphatase (AcUP)	Alkaline phosphatase (alkUP)	Urease (UU)
	-----μg p-nitrophenol g ⁻¹ h ⁻¹ -----			μg NH ₄ g ⁻¹ h ⁻¹
T ₁	45.8±22.12	117.9±34.95	184.3±95.35	119.3±40.03
T ₂	49.3±11.17	164.1±31.52	264.5±70.19	222.7±45.87
T ₃	69.8±42.4	269.5±44.03	372.6±151.76	230.7±103.04
T ₄	49.6±38.96	329.0±167.19	634.2±526.56	201.5±33.12
T ₅	50.2±16.60	117.1±8.43	304.0±163.48	146.5±57.18
T ₆	49.6±2.72	150.8±73.48	206.7±93.25	168.8±44.45
T ₇	65.2±5.94	251.4±47.36	366.0±75.54	151.1±8.06
T ₈	69.6±19.75	369.0±149.94	415.7±208.12	165.7±56.36
T ₁₇	26.74±8.02	138.7±47.6	219.2±51.16	258.3±38.64
T ₁₈	47.5±9.08	158.7±26.16	205.2±17.06	229.6±13.59
LSD ² _{...TR}	36.69	185.29	ns	ns
LSD ³ _{...OM}	18.91	112.9	ns	ns
LSD ⁴ _{...IN}	20.54	ns	ns	34.50

T: Treatment

¹ UBG and UP= μg p-nitrophenol g⁻¹ h⁻¹; UU= μg NH₄ g⁻¹ h⁻¹. Variation is expressed as standard deviation²Least significant difference; ³Compares compost vs control; ⁴ compares inoculated vs non inoculated

3.2.2. Effect of Compost application on Microbial Populations

Microbiological analysis revealed no significant effect of treatments on the evaluated microbial

populations, except on yeasts, where compost at minimum C level had the highest yeast concentration ($p < 0.0001$). On the other hand, the presence of inoculant tended to increase fungi populations (Table 5).

Table 5. Effect of compost applications on microbial soil populations

T	PSB	Actinomycetes	Fungi	Yeasts
	-----Log ₁₀ UFC g ⁻¹ -----			
T ₁	6.4±0.3	6.0±0.2	6.3±0.3	6.5±0.3
T ₂	6.2±0.5	6.0±0.2	6.2±0.3	6.5±0.4
T ₃	6.3±0.2	6.2±0.2	6.2±0.3	6.2±0.5
T ₄	5.2±1.4	5.7±0.6	5.8±0.8	7.4±0.3
T ₅	6.4±0.3	5.8±0.4	6.7±0.6	6.4±0.6
T ₆	6.2±0.3	6.6±0.3	6.3±0.2	6.7±0.4
T ₇	6.7±0.2	6.2±0.3	6.6±0.1	6.1±0.3
T ₈	6.4±0.2	6.6±0.3	6.5±0.4	5.8±0.2
T ₁₇	6.3±0.0	6.1±0.1	6.3±0.3	6.0±0.3
T ₁₈	6.4±0.4	5.9±0.4	6.7±0.2	6.5±0.4
LSD ² _{...TR}	ns	0.53	ns	0.65
LSD ³ _{...OM}	ns	ns	ns	0.54
LSD ⁴ _{...IN}	ns	ns	0.31	ns

T: Treatment

¹PSB: phosphate solubilizer bacteria. Variation is expressed as standard deviation.²Least significant difference; ³Compares compost vs control; ⁴compares inoculated vs non inoculated

3.2.3. Effect of compost application on agronomic variables: Effect on root development

Results indicated that the treatment including compost, microbial inoculant and chemical fertilizers (T_5) improved root growth development compared

to the other treatments. Root density showed a clear tendency to increase with compost rate. Additionally, the application of microbial inoculant potentiated this effect as shown in treatments that included it (Figure 3). Similar results were observed for shoot cross sectional area (data not shown).

Figure 3. Plant root density as a function of C rate from compost (C) in presence or absence of chemical fertilization (F) and inoculant (I)

The correlation analysis (data not shown) performed indicated that the effect of humic extract on pH and EC, root dry mass, enzymatic activity and microbial population were negatively correlated with these variables. Furthermore, a direct association between root density and available N, acid phosphatase, and β -glucosidase was found. It was evidenced that humic and fulvic acids, organic matter and WSC content were positively correlated with phosphatases and β -glucosidase potential activities, and soil yeast concentration.

4. Discussion

Vitis vinifera cv Thompson seedless is a fruit species cultivated in a wide range of soil types and climatic conditions. Normally, table grape requires the application of nitrogen, phosphorus, potassium, and some micronutrients such as iron, boron, manganese and zinc to reach high production levels and fruit quality (Palma, 2006; Tomasi, 2016). Nitrogen is one of the most important and limiting nutrients in table grape, particularly in spring season. Mineral N fertilizers

should be applied when table grape can absorb and assimilate N to build or supplement reserves, minimizing losses through leaching and denitrification processes. The period between “bloom” and “veraison” has a high N requirement (Palma, 2006). Besides, the available N will allocate and incorporate into permanent vine structures for storage when shoot growth is slow. During this period vines may accumulate up to 50% of annual N requirement. In contrast, the active root growth and mineral uptake is generally minimal during the budbreak period, thus N demand is supplied primarily from reserves stored in the roots and other permanent woody structures.

In the present study, compost supplied an equivalent rate of 36 kg of total N ha⁻¹ out of which, we estimated a maximum N mineralized of 10 kg N ha⁻¹ season⁻¹. This amount probably did not influence plant response as mineral fertilization. However, N requirements at establishment are low, reaching 30 kg N ha⁻¹. Flavel *et al.* (2005) indicated that grape marc compost applied in 0-10 cm depth in sandy soils of Australia increased 2.7% total N with high mineralization rates produced during the first days (2.4 to 7.4 mg N kg⁻¹ day⁻¹) in response to the decomposition of the soluble fractions of compost. The N supply derived from compost and other organic amendments should be considered in fertilizer programs; approximately 30% of the total nitrogen provided by compost is available during the season.

The mineral fertilizer applied in this experiment, Novatec Solub 21_{TM}, contains stabilized ammonium by the addition of the nitrification inhibitor 3,4 DMPP, which improves N use efficiency, reducing NO₃-N losses by leaching and denitrification, increasing N uptake (Molina and Ortega, 2006). Available N was larger in treatments including compost, which was probably associated to mineralization of organic N and/or lower N losses.

Additionally, humic and fulvic acids triggered positive effects on plants, stimulating root development by improved nutrient uptake, morphological changes, and larger chlorophyll leaf content, while in the soil have beneficial effects on pH, structure, water-air retention capacity, microbial population and acts a buffer solution in cation exchange capacity (Trevisan *et al.*, 2010). The present study showed an increase of HFa content with C rate, especially when compost was used, as a larger value was observed in the treatment composed by compost and microbial inoculant (T₈). These results can be explained by a larger microbial activity, based on the use of compost as substrate during mineralization of organic matter and HFa production. Additionally, a positive correlation was found between soil HFa content and both alkaline and acid phosphatases as well as with actinomycetes population, indicating the presence of hydrolytic bacteria. However, a negative correlation between HFa and dry root biomass was observed, probably since the application of humic extract increased pH and EC generating suppression on root growth. Humic extracts are associated with direct growth promotion effects related to hormone-like activity which can modified modify plant physiology (Nardi *et al.*, 2016).

Other studies have shown that large amendment rates increase soil carbon. Albaladejo *et al.* (2008) observed a 2-fold increase in soil carbon concentration after the application of 260 ton ha⁻¹ of uncomposted organic municipal solid waste. Furthermore, Morlat and Chausson (2008) showed that the accumulative rate of 256-320 ton ha⁻¹ of compost in vineyards during 16 year exhibited 2-fold increase on carbon concentration, respect to the control soil. In this experiment WSC concentration in soil improved with C rate, regardless of the C source; however, the rate of increase was larger for humic extract than for

the compost, probably due to the content of WSC in humic extract.

Diverse studies have associated compost application with the increase of soil enzymatic activities due to mineralization processes and microorganism activity (Martínez *et al.*, 2016; Ciaccia *et al.*, 2017). In contrast, other reports have indicated that the activity of enzymes such as proteases, urease and desaminases have decreased due to toxic effects caused by trace elements present in organic amendments (Heargreaves *et al.*, 2008). In the present study, a significant increase on β -glucosidase, acid and alkaline phosphatase potential activities was observed in compost treatments. Carbon sources as cellulose, lignin, starch, proteins, organic P, and other nutrients present in compost, besides the presence of microorganisms, stimulated biological activity and the continue mineralization process (Martínez *et al.*, 2016). In contrast, the humic extract contains C sources as polyphenolic compounds and very low microbial activity, due to its high EC and pH. Besides, urease activity decreased probably by application of compost and mineral fertilizer that maintained N-NH_4 levels in soil.

Additionally, organic amendments enhance soil microbial diversity that includes functional groups as mycorrhizal fungi and beneficial rhizosphere bacteria (Heargreaves *et al.*, 2008). Organic matter content is an important factor that influences microbial population, particularly by the presence of labile and organic sources of C. The results obtained in this study suggest that C treatments had a significant effect on yeast population, indicating that, probably, high C rates depressed the population by competence for substrate and space between native *terroir* yeasts and microorganisms added through compost. Furthermore, humic extract could suppress the microbial populations due to its high EC.

In contrast, other reports have reported that low concentration of humus-like substances extracted from compost stimulate the microbial population and vegetative biomass production.

According to the above-mentioned results, compost could be an economic and ecologic alternative to improve soil characteristics to induce plant growth promotion (Heargreaves *et al.*, 2008; Fincheira-Robles *et al.*, 2016). Composted grape pomace constitutes an important option to increase soil OM content improving physical, chemical and biological properties to soil ecosystem (Fincheira-Robles *et al.*, 2016). Ferrer *et al.* (2001) reported a positive effect using 1-4 ton ha⁻¹ of grape marc compost as a soil conditioner for corn seed germination in greenhouses, while Gaioti *et al.* (2016), showed that grape marc compost provided some benefit in returning nutrients into the vineyard. Moreover, Kim *et al.* (2015) reported that the mixture of compost, vermicompost and rice straw compost promoted the growth of root on soybean and sweet corn. In the present study, it was observed that compost generated an improvement on root synthesis and no negative effects were observed, suggesting an important role in promoting rhizogenesis, particularly in nursery vines. Probably, compost affects critical soil variables that induce root distribution of grapevines as texture, aeration, temperature, nutrient availability and organic matter content. Additionally, it was observed that compost in combination with mineral fertilizers and microbial inoculant, resulted in improved root density. Chemical fertilization provides elements required by the plant and microorganisms; compost generates an adequate environment in terms of physical and chemical conditions for availability of these nutrients, and the microbial inoculant provides beneficial microorganisms that mineralize organic matter, releasing more nutrients

and synthesizing humic substances (Ortega, 2015). Regarding the role of humic extract in root development, Ortega and Fernandez (2007) reported an increase in shoot and root biomass with C rate applied as humic substances, which was extracted from vermicompost and leonardite. In the present study, the high EC of humic extract caused negative effects in root development, despite the dilution performed before its application.

5. Conclusions

The use of compost as organic amendment during establishment of table grape improved the biological soil quality, favored the increased of humic and fulvic acids content and had a positive effect on root promotion in comparison with humic extract treatments and controls. The application of compost, mineral fertilization and microbial inoculant, as INM, produced the largest root dry matter. The use of humic extract must be done controlling the EC to avoid negative effects on biological soil activity and plant root synthesis. Additionally, it was possible to establish that phosphatases and β -glucosidase potential activity, WSC and soil humic and fulvic acids contents, are sensitive variables, which are strongly correlated with root growth (root density) and would be adequate to evaluate soil quality in table grape agroecosystems.

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