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ORIGINAL RESEARCH

Effect of the application of compost as an organic fertilizer on a tomato crop (*Solanum lycopersicum* L.) produced in the field in the Lower Valley of the Río Negro (Argentina)

Graciela Pellejero[1], Julieta Palacios[1], Emanuel Vela[1], Omar Gajardo[1], Luis Albrecht[1], Gabriela Aschkar[1], Amelia Chrorolque[1], Francisco J. García-Navarro[2], Raimundo Jiménez-Ballesta[3*]

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Abstract

Purpose The main objective of the study was to evaluate the application of different doses of onion residue compost as mixtures with bovine manure as organic fertilizers for a round tomato crop planted in the field.

Method The data were obtained experimentally in pilot fields. The experimental design was completely randomized, with 4 m^2 plots with ten plants each as an experimental unit and with three replications per treatment (2 years). Five treatments were tested, namely one unfertilized control, three with organic fertilization and one mineral treatment. The variables measured were plant height (cm), stem base diameter (cm), fresh plant weight (g) and total dry matter (%). The parameters measured for the fruit were fresh fruit weight (g), fruit length (mm), fruit width (mm) and total soluble solids.

Results The application of compost from the degradation of onion residues as mixtures with cow manure had positive effects on the growth of the plant and on the development of tomato fruit. Compost doses of 60 Mg ha^{-1} and 80 Mg ha^{-1} gave similar values to chemical treatment and the control without fertilization was significantly lower than those with doses of organic and chemical fertilizer. These results indicate that this compost contains the nutrients required by the tomato crop for growth and development.

Conclusion It was concluded that the agricultural use of quality compost is an effective strategy to obtain high quality products in an economically viable and environmentally sustainable way.

Keywords Compost amendment, Organic manure, Ecological, Cow manure, Plant nutrition, Río Negro

Introduction

In the Lower Valley of the Río Negro (Argentina) there has been an increase in the number of horticultural producers involved in, agro-ecological agriculture, where the tomato occupies a fundamental place alongside various other vegetables.

The concepts that fundamentally define agro-ecological agriculture require the exclusive use of organic products such as fertilizers from the degradation of organic residues, the use of crop rotation, pest control through the use of natural competitors and manual weed reduction (Canet and Albiach 2010). Likewise, some authors indicated that agro-ecological production contributes to an improvement in food security and the quality of the products consumed (Ozores-Hampton 1998; Mahmoudi et al. 2008; Nyantakyi-Frimpong et al. 2016; Pane et al. 2016; Pergola et al. 2020).

The use of municipal organic wastes, as outlined by Martínez-Blanco et al. (2011), involves replacing a fraction of the mineral fertilizer dosage with compost and this is a good option for food production. Thus, in response to the environmental problems caused by the excessive use of synthetic chemical fertilizers, agricultural cultivation with ecological techniques has been

✉ Raimundo Jiménez-Ballesta
raimundo.jimenez@uam.es

1 Nacional University of Comahue, CURZA, Viedma, Argentina
2 University of Castilla-La Mancha, Higher Technical School Agricultural Engineers of Ciudad Real, Ciudad Real, Spain
3 Autónoma University, Madrid, Spain

promoted extensively (Taylor et al. 2003). The use of organic fertilizers – such as compost and vermicompost – and the incorporation of technologies that reduce the sensitivity of crops to inclement weather and pests has mainly been targeted in the cultivation of vegetables (Gamliel and van Bruggen 2016).

In contrast to the above, the use of organic fertilizers for horticultural production has had a positive effect on the quality of the cultivated products, biomass production, yield (Singh et al. 2010; Doan et al. 2015), growth, flowering and fruiting (Peyvast et al. 2008; Moghadam et al. 2012). Above all, positive effects have also been observed in terms of soil conservation, quality and structure (Crittenden et al. 2015; Khan et al. 2015). This improvement is due to the increase in the content of organic matter, macro- and micro-elements (such as N, P, C, Mg, Si), the release of humic acids and increased biological activity in the rhizosphere, including short-term effects such as in short-cycle crops (Singh et al. 2006; Amaya-Carpio et al. 2009; Cruz Koizumi 2015). However, the positive responses observed vary and are closely linked to the geographical and ecological context where these agro-ecological practices are applied.

Following the idea of Rodrigo-Comino et al. (2018), it is possible to establish some fundamental principles and procedures depending of the geogrpahy of the site. In this way, Argentina is a country where it is necessary to implement measures for the proper use and management of the soil, being necessary to reuse certain wastes. Tomato (*Solanum lycopersicum* L.) is a key crop in Río Negro (Argentina) and in other parts of the world. Indeed, this crop represents the second highest economic activity in the primary agricultural sector and is a major generator and producer of food. The area cultivated with vegetables in Río Negro is 5000 ha and this is distributed in irrigated valleys. In addition to tomato, onion, pumpkin and, to a lesser extent, various other vegetables are cultivated in this province and there is a high potential for productive expansion based on agro-climatic conditions and the availability of suitable soils (Iglesias et al. 2004).

The nutritional quality of tomato fruits depends on several factors. Firstly, the amounts and types of chemical elements taken up from the soil and, secondly, the nature of the soil fertilization. Since tomato in the study area is grown in open fields, its cultivation can lead to erosion and loss of organic matter from the soils. It is therefore necessary to resort to sustainable practices that allow the recovery of these nutrients. The nutritional quality of tomato fruits depends on the amount and type of chemical elements taken up from soil and, as a consequence, different soil fertilization strategies can be used. One of the most viable and environmentally acceptable alternatives is the use of fertilizers and organic amendments, especially in agro-ecological production. The agricultural use of organic residues represents an attractive approach (Courtney and Mullen 2008 and Anwar et al. 2005), indicated that the combined application of manure and fertilizer helps to increase crop productivity and quality and to maintain soil fertility.

One of the most common and beneficial alternatives to traditional farming practices is to use quality compost obtained from cows. The composting process is one of the most widely used biotechnologies in agro-ecology for the production of organic fertilizers but it must be ensured that the initial residues do not contain contaminants that affect the system. The doses used must respond to the needs of the crops, the expected yields, the soil reserves and management practices, as well as the nutrient content of the compost and its release rate (Canet and Albiach 2010).

Organic products applied as fertilizers increase the growth, yield and quality of crops (Citak and Sonmez 2010; Faisal et al. 2017; Ye et al. 2020). These products also have physiological effects that include cell lengthening, vascular differentiation and production development (Luna Murillo et al. 2015). The degradation of organic waste is an efficient means of rational nutrient recycling and this aids plant growth and returns many of the elements extracted during the production process to the soil, (Ramos Agüero and Terry Alfonso 2014). The use of organic amendments improves soil productivity and health while generally providing a source of nutrients in organically managed systems, particularly in organic farming practices (Ramesh et al. 2009; Gopinath et al. 2009; Singh et al. 2010; Karimi et al. 2017). For the farmers, the application of swine manure to fertilize the soil can increase the yearly income, but it also may cause serious environmental problems related to soil health and soil quality (Antoneli et al. 2019). The addition of Vineyard composts supplemented with *T. harzianum* T78 represent a promising approach for the treatment and improvement of saline soil properties (Mbarki et al. 2017). The combining of MSW composts and alfalfa crop may be considered as a good strategy for saline soil remediation allowing alfalfa plant to mitigate the effect of salt stress and heavy metal pollution on soil environments (Mbarki et al. 2018).

In the context promoted in 2015 by the United Nations “the Sustainable Development Goals” (SDGs) to address the global challenges of our time (Müller and Weigelt 2013). In this way, the increasing pressure is on land calls for multi-use of land and for the restoration of degraded land (Visser et al. 2019; Keesstra et al. 2018). In particular, organic farming (that by príncipe does not make use of pesticides and artificial fertilizers), has proven to increase infiltration (Keesstra et al. 2019), in addition to reduce runoff, erosion and reduce nutrient loss (Di Prima et al. 2019).

The main objetive of the field experiment carried out in this study was to evaluate the efficiency of a compost made from onion residues generated in the Lower Valley as a mixture with cow manure as an organic fertilizer. The organic manure was applied at different doses to a tomato crop grown under ecological production conditions. A further aim was to compare the growth and quality of tomato in order to provide information that was relevant to the fertilization plan of ecological producers in this type of area.

Material and methods

The present study was carried out at the experimental station of the Agricultural Research Department of the National University of Comahue in Viedma (40º49´S), Río Negro (Argentina). The climate in this area is classified as semi-arid, mesothermal, with an annual average temperature of 14.1 ºC, with a thermal regime moderated by the maritime effect. The average annual precipitation is 394.2 mm and this has an almost homogeneous distribution throughout the year. Temperature data were supplied by the INTA Climatology Area of the city of Viedma. The soil features of the selected lot corresponded to an alluvial clay loam texture on a flat topography with the physicochemical characteristics are provided in Table 1.

The cultivation cycle was 100 days during 2018 and 2019. The size of the plant did not exceed 100 cm. The doses indicated in the treatments were defined according to the nitrogen criterion, which is the fundamental and most widely used approach as it is key for plant growth.

The treatments studied were as follows:

✓T1: Unfertilized witness

Table 1 Properties and composition of soil and compost used in the experiment

	pH (H_2O)	E.C. (ds m^{-1})	Ct (g kg^{-1})	N (g kg^{-1})	OM %	Pe (mg kg^{-1})	Ka (mg kg^{-1})	CEC (cmol kg^{-1})	Sand (%)	Silt (%)	Clay (%)
Soil	8.5	0.68	14	0.8	2.4	33.4	450	16.7	52.3	12.6	35.1
Compost	8.4	0.50	50	9	8.6	0.23	0.98	39.8			

E.C., electrical conductivity; Ct, total carbon; N, total nitrogen; OM, organic matter; Pe, extractable phosphorus: K, available potassium; CEC, Cationic exchangeable capacity.

✓T2: Chemical Treatment: Urea, (300 kg N ha^{-1}), phosphorus P_2O_5(45 kg ha^{-1}) and Potassium (320 kg ha^{-1}). Doses were determined according to the requirement of the crop and the contribution of the soil.

✓T3, compost, 40 Mg ha^{-1} (equivalent to 360 kg N ha^{-1})

✓T4, compost, 60 Mg ha^{-1} (equivalent to 540 kg N ha^{-1})

✓T5, compost, 80 Mg ha^{-1} (equivalent to 720 kg N ha^{-1})

The treatments were carried out in 4 m^2 plots (experimental unit), each containing 10 plants in a completely randomized design, which consisted of four treatments, with three repetitions per treatment. The planting frame at the final site was 0.70 m × 0.40 m with a single row (Fig. 1). The seeds (Determined round tomato ACE 55, for fresh consumption) were sown in 128-cell black polypropylene germination trays (seedling) with a capacity of 22 cm^3. A vermicompost-based substrate was used. When the seedlings reached the fourth and fifth leaves, they were transplanted to the plots at the final location. The same tillage was performed for all the plots in each field.

Prior to transplanting at a depth of 0.20 m, the full doses of compost were manually incorporated as organic fertilizer and the subsequent cultural tasks were carried out in accordance with the management practices of the ecological producer in the area. Chemical treatment was carried out by cultivation line in order to compare the results with those from the organic fertilizer. In the chemical treatment the fertilization was fractional, with nitrogen applied in the form of urea at two time points – the first at transplant and the second before flowering. Phosphorus was applied in the form of P_2O_5 to reach a dose of 45 kg ha^{-1} at the time of transplant and potassium was applied at a dose of 300 kg ha^{-1} at the time of transplanting and 60 days after the transplant. This management regime was consistent with that carried out by horticultural producers in the region. The plants were driven to a single stem and tutored. The drip irrigation system responded to the need for cultivation, using irrigation water with an electrical conductivity of 0.3 dS m^{-1} and a pH of 7.2. Weed control was carried out manually. Pest management was performed using natural products. Approximately 100 days after planting, the cycle was completed and the harvest of all the plants in the plot was carried out when the fruits had reached physiological maturity and quality for marketing.

Fig. 1 The planting frame in the field site. Laboratory determination of different tomato parameters

Ten plants were harvested per plot and these were divided according to leaf tissue (leaves and stem) and fruit. To evaluate the plant height, the measurement was taken from the base to the apex of the leaf taken at random within the useful plot and this was subsequently averaged, Fresh plant weight (g). Total dry matter (%) was determined after drying in a forced-air oven at a temperature of 60 ºC for five days until constant weight was obtained. The stem base diameter (cm) was determined with a digital caliper (Brand: KLD, Model: KLD1152) based on 5 cm from the ground to said measurement in 10 plants taken at random from the useful plot.

The selected fruits in a state of maturity (red color) all had a diameter greater than 45 mm and these are suitable for commercialization in the agro-ecological system of the area. Malformed fruits with apical rot or insect damage were discarded.

The parameters were determined according to the descriptors for tomato (*Lycopersicon spp.*), Baruch Bar-Tel (1996) for yield, ten fruits were randomly taken per treatment and per repetition and the following paraemters were evaluated: fresh fruit weight (g), fruit length (mm), fruit width (mm), soluble solids calculated with a refractometer (Handheld Refractometers MODEL REF108), with values expressed as Brix degrees, and the percentage of dry matter was determined by taking a sample in the equatorial zone of the fruits and drying it in an oven at 70 °C until constant temperature.

Statistical analysis

Statistical analysis was performed by analysis of variance (ANOVA) for each dependent variable. A probability level of 95% was employed to determine statistical differences. In the cases that presented significant statistical differences, mean comparisons were made using the 5 % Tukey test (InfoStat, Di Rienzo et al. 2018).

Results and discussion

Plant evaluation

The results for the variable plant height measured in the crop harvest showed significant differences ($p \leq 0.05$) between the control and the fertilized treatments (Fig. 2A). However, significant differences were not observed between chemical and organic treatments. Treatment 5, which had the highest dose of compost, gave the tallest plant height (103 cm) followed by the chemical treatment (96 cm). These results are consistent with those published by Rodríguez et al. (1998) and cited by Ochoa-Martínez et al. (2009), who reported that a greater plant height leads to a larger number of leaves. This increases the total photosynthetic activity, which in turn determines an increase in the weight of the fruit and consequently the yield. The differences between the control and the plants fertilized with organic fertilizer can be explained by a higher humidity retention. This property was shown by the substrates mixed with compost, which on average retained 14.21 % more moisture than those with mineral substrates, thus showing that the absorption of nutrients is more efficient (Castellanos et al. 2000). Guanoquiza and Abasolo (2017) carried out an investigation into different organic fertilizers versus chemical fertilizer but they did not observe significant differences in plant height between these treatments.

Regarding the variable stem diameter of the plant (Fig. 2B), significant differences ($p \leq 0.05$) were ob-

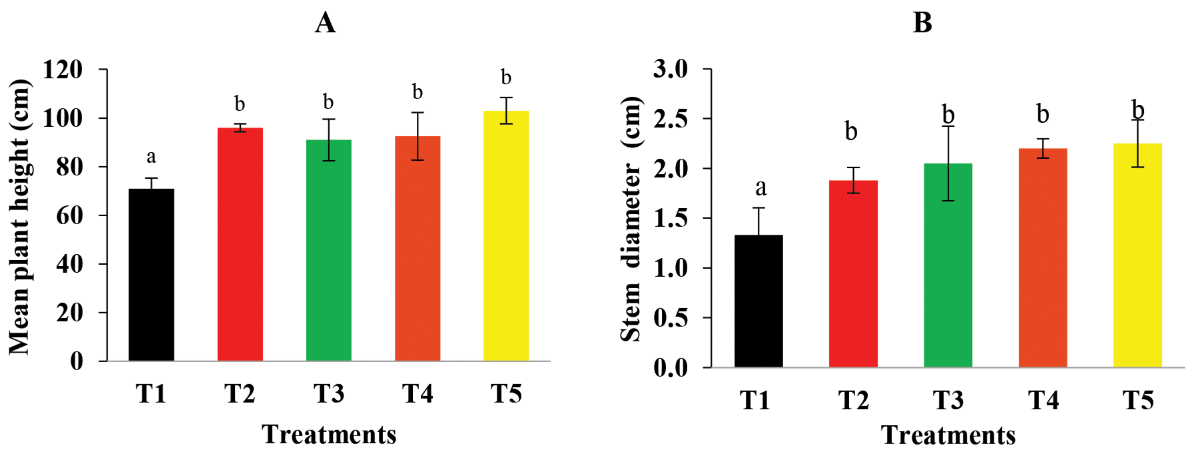

Fig. 2 Effect of different doses of compost on A: plant height (cm) and B: stem diameter (cm) of tomato (*solanum lycopersicum* L.)

T1, Witness unfertilized; T2, urea (300 kg N. ha^{-1}), phosphorus as P_2O_5 (45 kg. ha^{-1}) and P (360 kg); T3, compost (40 Mg. ha^{-1}); T4, compost (60 Mg. ha^{-1}); T5, compost (80 Mg. ha^{-1}). Different letters in bars of the same color indicate significant differences ($p \leq 0.05$). The vertical lines represent the standard error.

served between the control and the chemical and organic treatments. However, statistical differences were not observed between the chemical treatment and the compost treatments. The largest diameter (2.2 cm) was recorded for the chemical treatment and for the treatment with the highest dose of compost.

The variable fresh plant weight (Fig. 3A) showed significant differences between the control and the chemical treatment, T2 and 5 (80 Mg ha^{-1}). The highest fresh plant weight was observed for the chemical treatment, but this parameter does not differ from the organic treatment T5. Cifuentes et al. (2013) observed that fertilization with compost had a positive influence on the growth of tomato plants (*Solanum lycopersicum*). Treatments 3 and 4 did not differ from the control or T5.

The dry matter represents the amount of nutrients that the plant has accumulated during its growth and development. In the treatments evaluated, it was found that the unfertilized control registered the lowest dry matter value (20 %). Pineda-Pineda et al. (2011) stated that roots and leaves accumulated the highest amount of dry matter and absorbed more nutrients during the vegetative growth. Plant dry matter (Fig. 3B) showed significant differences between T1, the unfertilized control, and T5, compost (80 Mg ha^{-1}). The other treatments did not differ from the control. Treatments 2, 3, 4 and 5 did not differ statistically from each other, with the highest value of dry matter measured for treatment 4 (28 g) and treatment 5 (30 g).

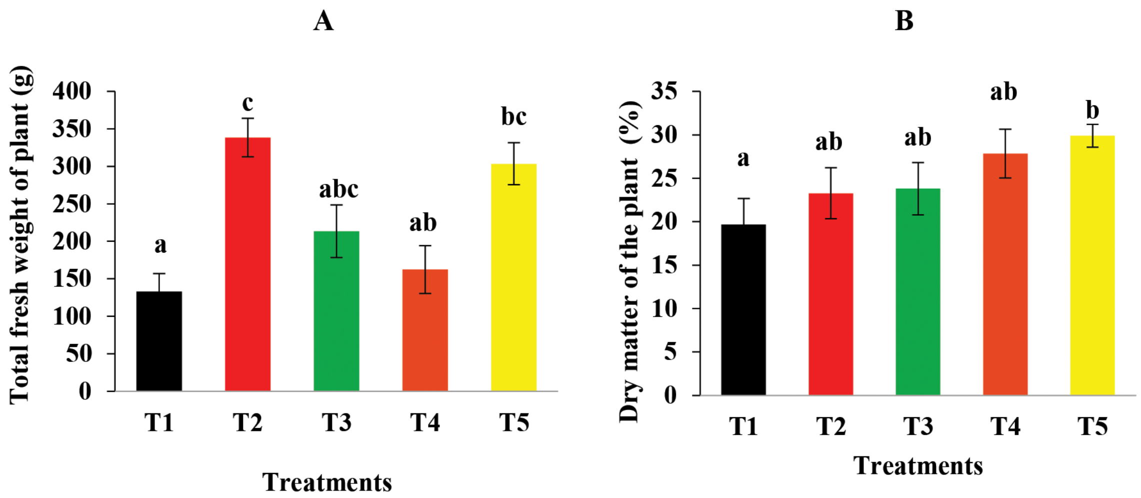

Fig. 3 Effect of different doses of compost on A: fresh weight of the plant (g) and B: dry matter of the plant (%) in tomato (*solanum lycopersicum* L.)

T1, unfertilized control; T2, urea (0.66 Mg ha^{-1}); T3, compost (40 Mg ha^{-1}); T4, compost (60 Mg ha^{-1}); T5, compost (80 Mg ha^{-1}). Different letters in bars of the same color indicate significant differences ($p \leq 0.05$). The vertical lines represent the standard error.

Fruit evaluation

Regarding the variables evaluated in fruit (Fig. 4A), the registered fresh weight values that indicated highly significant differences (p-value <0.001) between the unfertilized control, with an average weight of 165.38 g per fruit, and the fertilized treatments. The application of the highest dose of compost (T5) (80 Mg kg^{-1}) gave rise to the highest fresh fruit weight (173.86 g) but this did not differ statistically from the chemical treatment or from the other treatments with lower doses of compost. There is a coincidence with the work of researchers such as Arriaga (2015), who measured an increase in the weight of fruit fertilized with organic fertilizer of 13.62 % when compared to the chemical treatment. In all of the treatments evaluated, the application of organic fertilizer, regardless of the dose used, exceeded the control treatment, (Boudet Antomarchi et al. 2017). Luna Murillo et al (2015) recorded a higher fresh fruit weight in crops fertilized with organic fertilizer and this effect is based on the set of phytohormones present in the applied organic fertilizers, mainly the auxins described by Garcés (2002) and the humic substances of low molar mass, which have properties similar to those of the phytohormones present in organic fertilizers (Galy and Morard 2000; Clapp et al. 2001).

The dry matter levels in fruit indicate the amount of nutrients that it has accumulated depending on the fertilization applied. The dry matter of the fruits (Fig. 4B) showed significant differences between the control and the fertilized treatments (p-value <0.0001). Treatments 2, 3 and 4 were all very similar. Treatment 5 presented the highest value (6.1 g), with significant differences between this and the control and the other treatments, both chemical and organic.

Fruit width (AF) had the highest values for treatment 5 (56.2 mm), with a highly significant difference (p-value 0.001) when compared to the unfertilized control (Table 2). Treatment 3 also differed from the control treatment, with a value of 51.2 mm. Treatments 2 and 4 were the same as the control. Treatments 2, 3 and 4 did not show significant differences between one another. The highest value for fruit length (LF) was obtained upon treatment with the highest dose of compost, with a value of 68 mm (Table 2), while the control did not differ from treatments 2, 3 and 4.

Table 2 Effect of different doses of compost and mineral fertilizer on the width, length and soluble solids in tomato fruit

Treatments	AF (mm)	LF (mm)	SST (° Bx)
T1	44.0 a	54.2 a	4.0 a
T2	47.4 ab	61 ab	4.4 b
T3	51.2 bc	65 ab	4.6 bc
T4	49.6 ab	60.4 ab	4.6 bc
T5	56.2 c	68 b	4.8 c

AF:3 Fruit width (mm); LF: fruit length (mm); SST: soluble solids (degrees Brix); T1, unfertilized control; T2, urea (0.66 Mg ha^{-1}); T3, compost (40 Mg ha^{-1}); T4, compost (60 Mg ha^{-1}); T5, compost (80 Mg ha^{-1}). Different letters indicate significant differences ($p \leq 0.05$).

The soluble solid's values showed significant differences between the control treatment and the treatments with fertilizer (Table 2). Likewise, treatment with the

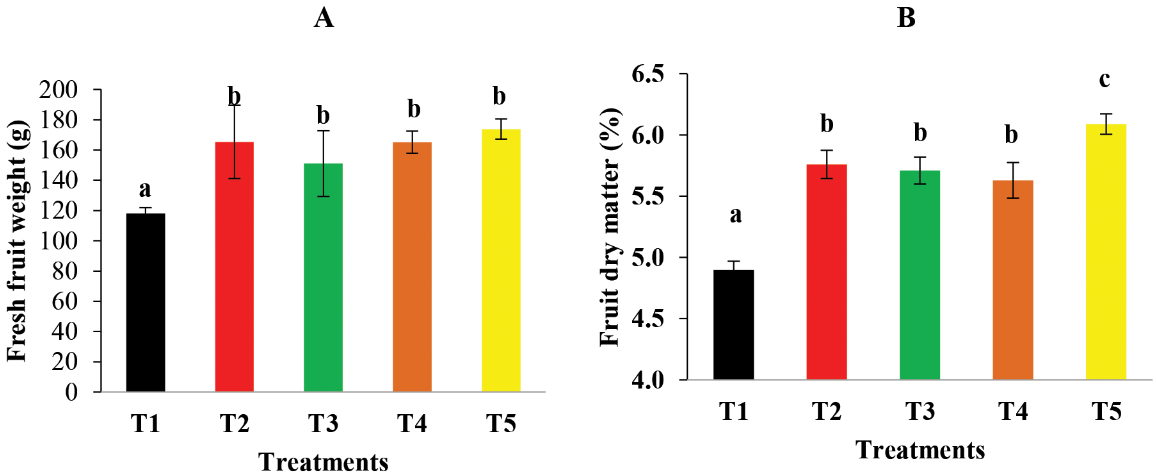

Fig. 4 Effect of different doses of compost on A: fresh fruit weight (g) and B: fruit dry matter (%) in tomato (*solanum lycopersicum* L.)

T1, unfertilized control; T2, urea (0.66 Mg ha^{-1}); T3, compost (40 Mg ha^{-1}); T4, compost (60 Mg ha^{-1}); T5, compost (80 Mg ha^{-1}). Different letters in bars of the same color indicate significant differences ($p \leq 0.05$). The vertical lines represent the standard error.

highest dose of compost was statistically different from the chemical treatment. The three compost treatments, with values of 4.6 and 4.8° Brix, were not significantly different.

Luna Murillo et al. (2015) indicated that the differences in fresh weight between unfertilized control plants and those treated with organic fertilizers could be due to the stimulation of the synthesis of various metabolites, such as amino acids and proteins, which would favor the accumulation of biomass. Another possible explanation is that organic fertilizers could promote the absorption of N-NO_3, which is related to the activity of H + –ATPases (Bittner et al. 2007; Canellas et al. 2010). These compounds are essential for growth, form part of the wide range metabolites, are involved in a large number of metabolic processes and are an integral part of many biomolecules that make up tissue. Authors such as Samburova et al. (2007); Vargas-García et al. (2008) and Elena et al. (2009), as cited by Luna Murillo et al. (2015), reported that a fertilizer consisting of humic substances stimulates some indicators of production of the crops such as the total fresh mass.

The chemical treatment – with a fruit length of 61 mm – did not show significant differences with the highest level of compost (T5). Boudet Antomarchi et al. (2017) obtained similar results for the width and length of the fruit, with the highest values observed when organic fertilizer was applied to the tomato crop. The increase in soluble solids depends on the level of starch, which hydrolyzes to produce sugars throughout the period of growth and development of the fruits. Free sugar comes mainly from glucose and fructose, which are found in more or less similar concentrations in tomato fruits. Furthermore, according to Herrmann (2001), the sugar content in the fruits is highly dependent on the light intensity. As a consequence, tomatoes grown in the open field have higher sugar contents.

It is clear that organic fertilizers provide fruits with a higher content of soluble solids. These results are consistent with those published by Gutiérrez-Miceli et al. (2007), who reported higher soluble solids contents in tomato crops fertilized with compost. Ochoa-Martínez et al. (2009) recorded similar values of soluble solids in tomato fruit after organic treatments, with values of 4.5 and 4.7° Brix, and mentioned that organic treatments generated better quality fruits since the optimal value is 4.6° Brix (Diez 2001).

In accordance with some antecedents that indicate that the nutrients present in compost can cover the nutritional requirements of the tomato, either partially or totally (Márquez and Cano 2005; Raviv et al. 2004, 2005; Raviv 2005), our results indicate a clear difference between the experimental proposal. Compost obtained from the degradation of onion residues, when mixed with cow manure (as one of the organic products in the composting process), has distinct advantages over other organic fertilizers, e.g., the rate of mineralization of nutrients, with reports of 70 to 80% phosphorus, 80 to 90% potassium, and 11% of nitrogen, all of which remain available for the plant in the first year (Eghball 2000; Aram et al. 2005; Rosen and Bierman 2005).

For the reasons discussed above, the agricultural use of quality compost is strongly recommended as an economically and environmentally friendly strategy. Furthermore, since organic matter is usually lost, this cultivation method will improve this property.

Conclusion

The application of compost obtained by the degradation of onion residues, in a mixture with bovine manure, had positive effects on the growth of the plant and on the development of tomato fruits. All treatments gave rise to higher values than the unfertilized control. Compost doses of 60 Mg ha^{-1} ~~kg.m^{-1}~~ and 80 Mg ha^{-1} ~~kg.m^{-1}~~ gave similar results to the chemical treatment and the control without fertilization was significantly poorer than the samples treated with organic and chemical fertilizer.

For all of the measured variables, there were significant differences (with an error $p < 0.05$) between the unfertilized control and the treatments with compost and mineral fertilization. Likewise, the height of the plant and the diameter of the stem of the plant did not differ for the treatments with organic and chemical fertilizer. In terms of fresh plant weight, the chemical treatment gave the highest values and these were significantly different from the organic treatments at the lower doses (compost at 40 and 60 Mg ha^{-1}). However, the highest dose of compost (80 Mg ha^{-1}) gave very similar results to the organic fertilizer. The results indicate that replacing the dosage of mineral fertilizers with compost is a good option as this approach would allow the agro-ecological producer to make use of this organic fertilizer, which is available in the Lower Valley itself without the need to consider neighboring areas in search of organic fertilizer. Further studies more than two years are needed to provide more evidence of the advantages outlined here.

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Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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