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Analysis of the Yield of Radish (Raphanus Sativus L.) Fertilized with Compost Based on Organic Waste from Markets and its Relationship with its Stomatal Density

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For higher yields in vegetable cultivation, the availability of soil nutrients must be improved. Therefore, the aim of this research was to establish the relationship between stomatal density and the yield of the radish crop fertilized with compost made from organic market waste. A completely randomized block design was used, which consisted of 3 blocks and 5 treatments, which were T1, T2, T3, T4 and T5 with 00, 10, 15, 15, 20 and 25 g compost/plant respectively. The physical characteristics of the plants were evaluated from sowing to harvest and the data obtained were processed by analysis of variance and Duncan's test. Chemical analysis of the compost and soil was carried out, as well as a foliar analysis to determine the nutrient concentration by treatment. The results determined that the treatment (T4) stood out in plant length with 28.96 cm, plant weight with 43.33 g, yield of 10.82 t/ha and bulb diameter of 3.92 cm; likewise, in the concentration of nutrients in the leaves, the treatment (T5) highlighted in N with 5.94%, Ca 4.84%, Mg 1.29%, Zn 64.58 ppm and a stomatal density of 642 stomas/mm^2. It is concluded that, at an adequate dose of compost, the concentration of nutrients increases, as well as the stomatal density, resulting in higher yields.

1. Introduction

The aim of the present research is to obtain compost from organic solid waste, mainly composed of fruit and vegetables, generated in food markets, where significant amounts of food are lost daily, a situation that has become a global concern because it affects food security (Vågsholm et al., 2020). In this regard, Abadi et al. (2021) point out that the lack of environmental management and education in these establishments generates volumes of unnecessary waste that end up in landfills, wasting their potential for recovery and recycling.
Composting is one of the applicable techniques to recycle organic debris in an added value product. It allows the transformation and stabilization of organic waste into biofertilizers that can be safely applied to land and crops (Lim et al., 2017). Compost is a product appreciated for containing a high percentage of humic substances which is used as a soil improver, organic fertilizer and as part of seed culture substrates, so all organic materials of plant or animal origin, which contain a large amount of biodegradable organic matter in their composition, can be used in their production (Hannibal et al., 2016). Also, it should be taken into account that the basic chemical characteristics of the compost are neutral pH (7.96–8.10), 24.5–24.70% of organic matter, favourable C/N ratio, and represents a stable substrate for the application (Milinković et al., 2019).
In this sense, the highlight of this work is that the composting process, in addition to contributing to the reduction of waste going to landfill by using it as plant nutrients, will also help to reduce greenhouse gases as suggested by Kamyab et al. (2015).

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2. Materials and methods

This research was carried out during the months of May and June, in the population centre called Medio Mundo, located in the district of Vegueta in the Lima region, with an average minimum and maximum temperature of 18 °C to 23 °C respectively and a relative humidity ranging from 78 to 83% on average.

2.1 Study factor

In order to establish the doses of compost, we took into account what is used by farmers in the area, who usually use an average of 6 to 10 t/ha for the cultivation of vegetables. This is supported by Hirzel and Salazar (2016), who mention that the application of a referential dose of organic amendments is 4 to 8 t/ha for semi-compost and 6 to 12 t/ha for compost. Table 1 shows the measurements of the compost doses applied to the radish (Raphanus sativus L.) crop.
The application of doses of compost was carried out 7 days after transplanting (when the plant reached 45 days after sowing). For this purpose, the common dose and the control were taken into account; according to Hirzel and Salazar (2016), they indicate that the reference dose of organic amendments is 4 to 8 t/ha of semi-compost and 6 to 12 t/ha of compost. It should also be mentioned that the field work was the same for all the plots, and only the dose of compost was varied. Table 1 below details the amounts of compost for each treatment.

Table 1: Compost application doses by treatment

Treatment	g/plant	t/ha
T1	00	0
T2	10	4
T3	15	6
T4	20	8
T5	25	10

2.2 Procedures

The compost was made from organic solid waste generated in the supply markets, which was composted for 3 months. From the compost obtained, 1 kg sample was taken for a complete analysis of elements at the National Institute for Agrarian Innovation (INIA). Subsequently, soil samples were taken in a staggered manner at a depth of 25 cm, which were poured into a blanket for mixing, from which a sample of 1 kg was taken and sent to INIA for the realization of its chemical analysis. Radish plants (Raphanus sativus L.) were sown at a distance of 0.10 m between plants and 0.5 m between twin rows. At 10 days, the compost doses of the different treatments were applied to the plants, as detailed in table 1. During harvesting, physical characteristics were assessed and leaf samples were taken to determine the concentrations of macro and microelements. Finally, stomatal density was determined by electron microscopy analysis in order to determine the relationship between yield and the number of stomata present on the leaves.

2.3 Statistical application

Data obtained after harvest were processed using the analysis of variance method. The result was compared with the data from the Fisher's F distribution table at 5% error to evaluate its significance as shown in Table 2; that is, if there was an effect of doses on the physical characteristics.

Table 2: Analysis of variance for blocks and treatment

Source of Variation	SC 2	DF	CM	Model I E(CM)	Model II E(CM)	F. cal
Blocks	SC_b	b – 1	$CM_b=SC_b/b-1$	$(\sigma^2_e + \sum\beta^2_j)/(b-1)$	$\sigma^2_e + t\sigma^2_\beta$	CM_b/CM_e
Treatments	SC_{tr}	T – 1	$CM_{tr}=SC_{tr}/t-1$	$(\sigma^2_e + b\sum T^2_i)/(t-1)$	$\sigma^2_e + b\sigma^2_t$	CM_{tr}/CM_e
Error	SC_e	(b-1)(t-1)	$CM_e=SC_e/(b-1)(t-1)$	σ^2_e	σ^2_e	
Total	SC_t	bt – 1				

Source: Núñez and Tusell (2007).

Duncan's test at 5% error was used when the results of the analysis of variance determined significance in the variables evaluated. It is worth mentioning that by means of this statistical analysis it was possible to specify which treatment stood out in relation to the others and if there was homogeneity or differentiation in the treatments.

3. Results and discussion

The results of the soil analysis are shown in Table 3, which, according to the classification of Prialé (2016), the value of electrical conductivity corresponds to a very slightly saline soil, the pH corresponds to a neutral value, organic matter and nitrogen have low values, and phosphorus and potassium show average values. As for the interchangeable cations, according to McKean (1993), we have a high value for Ca, and average values for Mg, Na and K; and for the cationic exchange capacity, we have a low level according to Garrido (1994).

Table 3: Basic soil analysis for sugar beet cultivation

E.C.	pH	O.M.	N	P	K	$CaCO_3$	Interchangeable cations (mEq/100 g soil)				CEC
mS/cm		% mass	% mass	ppm	ppm	% mass	Ca	Mg	Na	K	
0.73	8.0	0.51	0.03	17.05	115	5.72	5.95	1.76	0.09	0.28	8.08

Source: National Institute for Agricultural Research, INIA (2021). Laboratory 105-108. Huaral.

ppm: Parts per million.
CEC: Cation exchange capacity.
OM: Organic matter.
EC: Electrical conductivity.
Table 4 shows the chemical analysis of the compost expressed as a percentage by mass, where a higher percentage of organic matter and a low concentration of the microelements N, P, K can be observed. Likewise, the pH is alkaline with a value of 8.54, the C/N ratio is 7, the humidity is 10.82% and the electrical conductivity is 4.22 mS/cm. This shows that by increasing the pH, the concentrations of macro and microelements decreased; however, the C/N ratio is within the favourable margins for compost decomposition, mineralization and availability of nutrients for the development of the plant, so that this organic fertilizer is within the appropriate conditions to be used as a compost. In this regard, Tibu et al. (2019), states that the concentrations of nutrients in the compost vary with an increase in pH (up to 9.2), affecting the concentrations of K and Ca below the expected values; likewise, the concentrations of N and P are adequate, as are the humidity, the amount of organic matter present and the C/N distribution on a dry basis, which has an average value of 7.

Table 4: Chemical analysis of compost

E.C. 1:5	pH 1:2.5	Humidity	O.M.	N	P_2O_5	K_2O	CaO	MgO	C/N
mS/cm		%	%	%	%	%	%	%	%
4.22	8.54	10.82	12.93	1.06	2.17	0.65	1.81	1.30	7.07

Source: INIA, 2021**.**

The concentrations of the microelements present in the organic compost used to fertilize the radish crop were determined: Fe 4583.03 ppm, Zn 79.22 ppm and Cu 12.53 ppm. It can be seen that the compost based on organic market waste has a higher concentration of iron than vermicompost, which according to Román et al. (2013), contains 0.02% iron; However, Zn and Cu have a lower percentage compared to other organic fertilizers such as Bocashi, which according to Pérez et al. (2008), has a higher percentage of Zn with 0.0249% and Cu with 0.0139%, but in Fe is within the margins. Therefore, this organic fertilizer based on market waste is within the appropriate range, as its nutrient supply is adequate for plant development.
Regarding the foliar analysis that is appreciated in Table 5, it is observed that as the doses of compost increased, the concentrations of N, Ca, Mg and Zn increased and the concentrations of Na, P, K, Cu and Fe decreased. An increase in Fe was also noted in the T4 treatment, which corresponds to a higher yield in the radish crop, according to table 6, so that the T4 treatment can be considered as an indicator of nutrient concentration. This differentiation is due to factors such as the availability of nutrients incorporated in the compost, as well as environmental and phytosanitary factors that directly influenced the biochemical reactions of the nutrients. Morón et al. (1999), argue that leaf analysis is dependent on plant type, which is reflected in the ranges of deficiency, normality and toxicity between species and cultivars, even when comparisons are made at the same physiological age.

Table 5: Complete analysis of leaves of radish (Raphanus Sativus L.) according to the doses of compost

Percentage			Treatments		
(%)	T_1	T_2	T_3	T_4	T_5
N	5.49	5.26	4.76	4.82	5.94
P	0.33	0.38	0.37	0.34	0.33
K	5.38	4.84	4.44	3.90	3.48
Ca	1.47	3.66	1.90	4.80	4.84
Mg	1.03	1.15	1.13	1.18	1.29
Na	2.35	1.09	0.71	0.73	0.75
parts per million (ppm)					
Cu	5.62	5.60	6.12	5.63	5.33
Fe	2957.18	2485.88	2597.43	3065.17	2679.41
Zn	55.90	54.72	54.74	49.04	64.58

Source: INIA, 2021.

Concerning the statistical processing of the physical characteristics of the radish crop given in table 6, it is observed that there was no significance between the evaluated physical characteristics and the treatments. However, the T4 treatment corresponding to 20 g of compost/plant was superior to the others in terms of yield and bulb quality; this is due to the increase of nutrients in the soil and therefore a greater availability of nutrients, which has an optimal influence on plant development. D'Eletto et al. (2018) refer that the incorporation of compost had significant effects on the foliar area during two consecutive lettuce crop cycles, with a greater number of leaves in the spring cycle with the highest doses of compost. The combination of greater leaf area and greater number of leaves has an impact on crop productivity.

Table 6: Physical characteristics of radish (Raphanus Sativus L.) cultivation

Treatment	Compost dosage (g/plant)	Plant length (cm)	Plant weight (g)	Yield (t/ha)	Bulb diameter (cm)
T_4	20	28.96 a	43.33 a	10.82 a	3.92 a
T_5	25	28.65 ab	41.33 a	10.22 ab	3.87 a
T_3	15	28.35 ab	41.00 a	10.06 ab	3.82 a
T_2	10	27.88 ab	38.00 a	9.17 ab	3.73 a
T_1	00	27.16 b	36.33 a	8.60 b	3.40 a
Significance		**	**	**	**
CV (%)		7.12	6.35	11.80	8.14

CV: Coefficient of variation.
** Not significant
Letters a and b are score groupings according to Duncan's test, where different letters indicate significant differences between the compared means (Balzarini et al., 2015).

Table 7 shows the number of stomata and stomatal density of radish leaves, which were quantified from images obtained with a scanning electron microscope at 800X magnification (Figure 1). It is observed that, as the compost doses were increased, the number of stomata increased, with the T5 treatment standing out with 91 stomata, which is equivalent to a density of 642.0 stomata/mm^2. However, T4 with 63 stomata and a density of 444.60 stomata/mm^2 obtained the highest yield with 10.82 t/ha (see table 6), so it can be deduced that this treatment made efficient use of nutrients in the formation of carbohydrates, thus increasing the yield. In this regard, Álvarez et al. (2018), argue that stomata characteristics and their concentration may be determinant factors in differences in biomass production; however, Toral et al. (2010), state that stomata size, density and stomata index vary with latitude, but may be associated with changes in photoperiod, water availability and soil conditions.

Table 7: Stomatal density of radish (Raphanus Sativus L.) leaves per treatment

Evaluation			Treatments		
	T_1	T_2	T_3	T_4	T_5
Stomatal density (number of stomata/mm^2)	338.74	317.57	176.45	444.60	642.06
Number of open stomata/mm^2	48	45	25	63	91

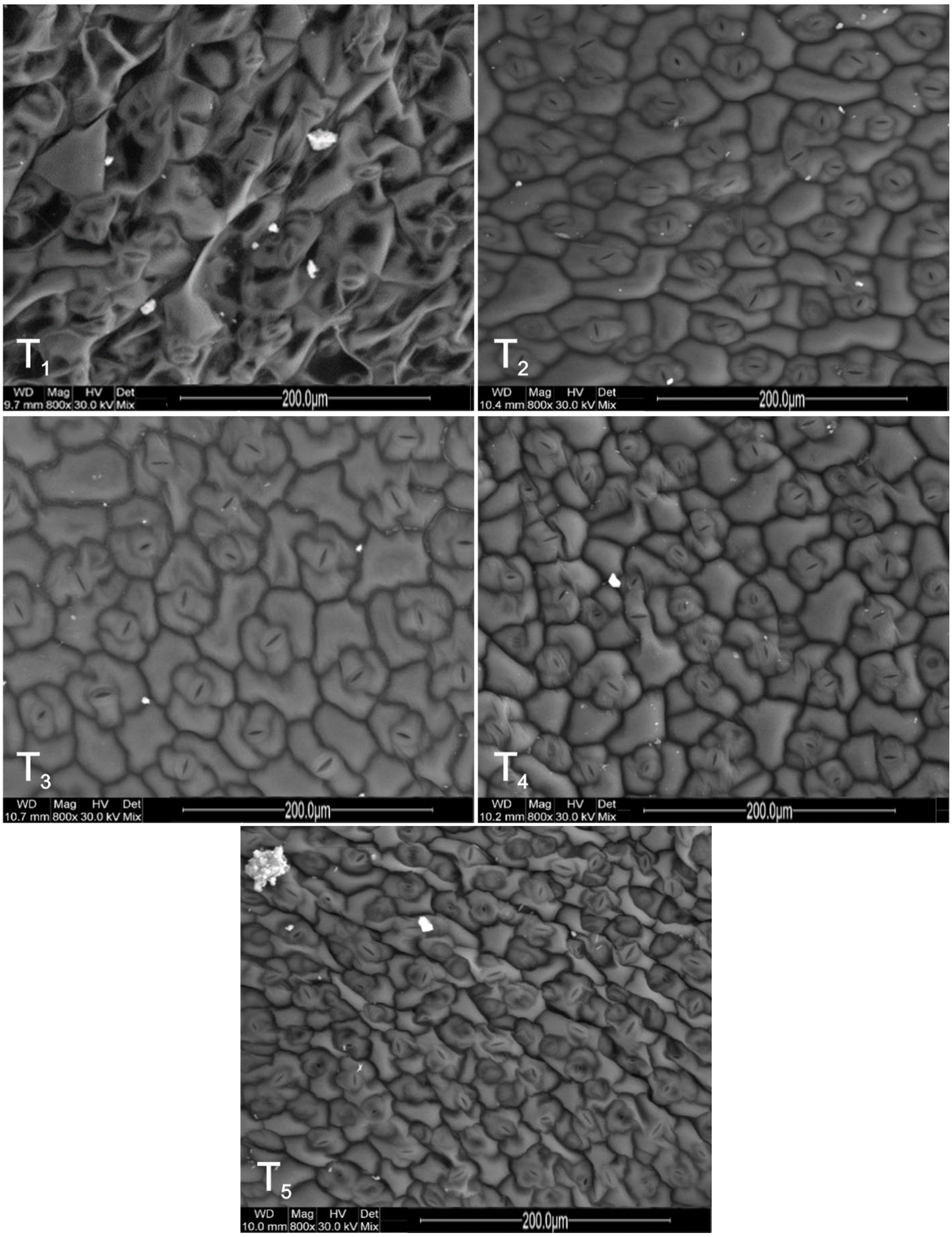

Figure 1: Scanning electron microscope photograph of the stomata of radish (Raphanus sativus L.) leaves for each treatment.

4. Conclusions

It was determined that the highest number of stomata was obtained with the T5 treatment with 91 stomata which is equivalent to a stomatal density of 642.06 stomata/mm^2; however, the T4 treatment with 63 stomata and 444.60 stomata/mm^2 obtained the highest yield. Therefore, the T4 treatment is taken as an indicator of the number of stomata to obtain a higher yield, since in this number of stomata the nutrients for the formation of carbohydrates were efficiently used.

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