Brazilian Journal of Biology®

ISSN 1519-6984 (Print)
ISSN 1678-4375 (Online)

Original Article

Analysis of the chemical and biological characteristics and their relationship with the yield of radish *(Raphanus sativus* L.*)* nourished with compost based on plant residues

Análise das características químicas e biológicas e sua relação com o rendimento do rabanete (*Raphanus sativus* L.) nutrido com composto à base de resíduos vegetais

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Abstract

The increase in fertilizer prices was 20% after the pandemic, which increased the cost of crop production in Peru. For this reason, research was conducted on the analysis of the chemical and biological characteristics and their relationship with the yield of radish nourished with compost based on plant residues. The objective was to analyze the chemical and biological characteristics and their relationship with the yield of radish nourished with vegetable waste-based compost. It is based on the methodology applied with an experimental approach; therefore, the statistical model of the Completely Randomized Block Design was used, which consisted of 3 blocks and 5 treatments that were T_1 with 0, T_2 with 4, T_3 with 6, T_4 with 8 and T_5 with 10 t/ha of compost based on vegetable residues, and the doses were applied 14 days after sowing. Physical characteristics (total plant length, plant weight, bulb equatorial diameter and marketable yield), nutrient concentrations (nitrogen, potassium, phosphorus, calcium, magnesium, sulfur, molybdenum, iron, manganese, copper, zinc, boron, chlorides and sodium) in leaves and stomata density were evaluated. The results determined that T_5 stood out in total plant length with 28.07 cm, plant weight with 75 g, bulb equatorial diameter with 4.52 cm and commercial yield with 22.53 t/ha. In the total contribution of nitrogen in relation to yield with 300.44 kg/ha. Profitability with 186.8%. Quantification of stomata per treatment with 598 stomata/mm^2 and concentration of nutrients in leaves at T_3 with nitrogen, potassium, phosphorus and magnesium. It concludes that T_5, which has an adequate concentration of nutrients in leaves such as magnesium, manganese, zinc and stomata density of 598 stomata/mm^2 influenced optimal biochemical reactions that resulted in the highest yield with 22.53 t/ha, differing by 31.38% in relation to T_1.

Keywords: plant residues, compost, dosage, nutrients, stomata, yield.

Resumo

O aumento dos preços dos fertilizantes foi de 20% após a pandemia, o que aumentou o custo da produção agrícola no Peru. Por esse motivo, foi realizada uma pesquisa com o objetivo de analisar as características químicas e biológicas e sua relação com o rendimento do rabanete nutrido com composto à base de resíduos vegetais. Baseia-se na metodologia aplicada com abordagem experimental; portanto, foi empregado o modelo estatístico do Delineamento em Blocos Completamente Casualizados, que consistiu em 3 blocos e 5 tratamentos que foram T1 com 0, T2 com 4, T3 com 6, T4 com 8 e T5 com 10 t/ha de composto à base de resíduos vegetais, e as doses foram aplicadas 14 dias após a semeadura. Foram avaliadas as características físicas (comprimento total da planta, peso da planta, diâmetro equatorial do bulbo e produtividade comercial), concentrações de nutrientes (nitrogênio, potássio, fósforo, cálcio, magnésio, enxofre, molibdênio, ferro, manganês, cobre, zinco, boro, cloretos e sódio) nas folhas e densidade de estômatos. Os resultados determinaram que o T5 se destacou em comprimento total da planta com 28,07 cm, peso da planta com 75 g, diâmetro equatorial do bulbo com 4,52 cm e produtividade comercial com 22,53 t/ha. Na contribuição total de nitrogênio em relação à produtividade com 300,44 kg/ha. Rentabilidade com

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Received: February 14, 2024 – Accepted: August 5, 2024

186,8%. Quantificação de estômatos por tratamento com 598 estômatos/mm^2 e concentração de nutrientes nas folhas no T3 com nitrogênio, potássio, fósforo e magnésio. Conclui que o T5, que possui concentração adequada de nutrientes nas folhas como magnésio, manganês, zinco e densidade de estômatos de 598 estômatos/mm^2, influenciou reações bioquímicas ótimas que resultaram na maior produtividade com 22,53 t/ha, diferindo em 31,38% em relação ao T1.

Palavras-chave: resíduos vegetais, composto, dosagem, nutrientes, estômatos, rendimento.

1. Introduction

The increase in fertilizer prices was 20% after the pandemic, which increased the cost of crop production in Peru. This increase caused considerable damage to farmers, leading to a social and food crisis that worsened even more in the interior of the country. In this regard, Legua Cárdenas et al. (2023) state that Peru has been adversely affected by the increase in fertilizer prices by more than 25% compared to previous years. Castañeda Chirre et al. (2022) mention that the increase in fertilizer prices in Peru, such as Urea, Diammonium Phosphate, Potassium Sulfate, Nitrate and other products necessary for agriculture, has affected vegetable production, which influenced food prices.

Due to this situation, it is necessary to innovate in sustainable alternatives to supply nutritional products. In this case, it is possible to take advantage of the residues generated in the field, such as vegetable residues from peas and other vegetables, which have a concentration of nutrients such as N, P, K and other elements involved in the development, strengthening and yield of the plant. The aforementioned is supported by the study of Cajusol and Moisupe (2019), who determined that cattle manure, sweet potato stubble, corn, sorghum and grass pruning remains presented carbon (18.70% to 44.86%), nitrogen (0.78% to 2.10%) and C/N ratio of 13.15 to 56.08, demonstrating that agricultural solid residues can be used as fertilizers. Also Pérez Leal (2017) evidenced that through analytical chemistry techniques and micromethods, elements were identified in vegetables in 100 g of dry matter as carbon with 45%, oxygen with 45%, hydrogen with 6%, nitrogen with 1.5%, calcium with 0.5%, potassium with 1%, sulfur with 0.1%, phosphorus with 0.2%, magnesium with 0.2% and silicon with 0.1%.

It is important to mention that by applying compost based on pea, bean and other vegetable residues to the soil, physical, chemical and biological properties are improved, which favors nutritional conservation and plant development. According to Argote (2016), he exposes that by applying rice straw compost mixed with manure in a 3:1 ratio to the soil and then analyzing the soil in the laboratory, it was determined that there was a slight increase in soil organic matter and porosity was maintained. In addition, Cardona and Hernández (2008) determined that pruning residue compost (grasses, dry leaves, etc.) has a good cation exchange capacity (CEC) and can be used as an organic amendment to improve soil properties.

On the other hand, Arce-Insuasty et al. (2019) highlight that in the laboratory it was determined that pea pods, with a dry weight of 30 g, contain 39.6% carbon, 3.77% nitrogen and 5.25% hydrogen, while the foliage, also with 30 g dry weight, contains 40.5% carbon, 3.05% nitrogen and 5.25% hydrogen. Therefore, these amounts in pods and foliage indicate that this legume is an important source of carbon and nitrogen for composting.

For this reason, research was conducted on the analysis of the chemical and biological characteristics and their relationship with the yield of radish nourished with vegetable waste-based compost. The objective was to analyze the chemical and biological characteristics and their relationship with the yield of radish nourished with vegetable waste-based compost. Therefore, the statistical model of the Completely Randomized Block Design was used, consisting of 3 blocks and 5 treatments.

Finally, the purpose of this research is to take advantage of the vegetable residues generated in the field to give them an added value as compost. This fertilizer is a nutritional source that, in adequate doses, will serve as a recommendation for farmers in the area.

2. Materials and Methods

2.1. Type of research

It is based on applied research with an experimental approach; since through continuous evaluations of the samples, the adequate dose of compost based on vegetable residues was obtained to obtain higher radish yields.

2.2. Population

The population consists of radish plants, which are grown from 50 to 150 meters above sea level. Therefore, the data obtained in the experiment were validated.

2.3. Sample

The sample consisted of 20 plants, which is equivalent to 31.25% of 64 plants per plot that were marked for the evaluation of physical characteristics. These were taken from the center rows of the 2 twin rows in order to avoid the edge effect.

2.4. Study factor

The doses of compost based on plant residues were established according to the soil analysis obtained from the National Institute for Agrarian Innovation (INIA) - Huaral. We also considered what farmers in the area apply, which is 6 to 8 tons per hectare, and the recommendation of Hirzel and Salazar (2016), who mention that 6 to 12 t/ha of compost based on vegetable by-product residues or compost from a mixture of animal and vegetable by-products should be applied. Therefore, the standard dose was set at 6 tons per hectare and the planting, fertilization and phytosanitary control tasks were carried out in the same way (See Table 1).

2.5. Determination of the amount of nitrogen in the soil

Calculation of the arable soil layer per hectare

To determine the weight of the arable layer, the Formula 1 of Ipanaqué (2023) shall be applied.

$$[Weight\ Ha] = (P.\ soil)\ x\ (D.ap.)\ x\ (Ha) \quad (1)$$

where: Weight Ha: Soil weight of the arable layer per hectare; P. soil: Depth of soil (0.20 m); D.ap.: Apparent density (1.4 g/cm^3); Ha: Hectare (10 000 m^2); Weight Ha: 2800 t/ha of soil.

2.6. Determination of organic carbon

Van Bemmelen's formula was applied which is [Organic C.]= (M.O.x 0.58) (Vela et al., 2012; Formula 2).

$$[Organic\ C.] = (M.O.\ x\ 0.58) = (1.42\% * 0.58) = 0.8236\%. \quad (2)$$

where: C. Organic: Organic carbon; O.M.: Organic matter with 1.42% (Table 2) (INIA, 2023a).

2.7. Quantification of carbon/nitrogen ratio (C/N)

The values were replaced using the Formula 3 for the carbon and nitrogen ratio.

$$C/N = (1.42\%\ x\ 0.58)/0.07\% = 0.8236/0.07 = 11.76 \quad (3)$$

where: C. Organic: Organic carbon; N: 0.07% N (nitrogen) (Table 2) (INIA, 2023a); C/N: Carbon/Nitrogen ratio 11.76.

Obtaining the value of the C/N ratio, which is 11.76, was taken as an indicator within the margins of the C/N ratio that is in the conversion table of total nitrogen to available nitrogen (See Table 3).

After comparing the C/N ratio indicator, which has a value of 11.76, it was determined that it is within the C/N ratio range of 10 to 12, which is equivalent to 140 ppm of nitrogen. Next, the Available Nitrogen (N.D.) formula was applied, which is equal to 140 ppm of nitrogen multiplied by 0.07 of soil nitrogen (Table 2) (INIA, 2023a). The result was 9.8 ppm of N.D. Subsequently, this amount was projected by the weight of the arable layer of the soil, which is 2800 t/ha of soil, obtaining 27.44 kg/ha of N.D.S. (Soil Available Nitrogen).

2.8. Determination of the standard dose of compost in relation to nitrogen

The standard dosage of compost based on plant residues was determined as follows:

The amount of nitrogen was taken from the fertilization recommendation of INIA - Huaral, which is 180 kg/ha of N (Table 4) (INIA, 2023b). From this value, 27.44 kg/ha of N.D.S. were subtracted, resulting in 152.56 kg/ha of N.D.A. (Available Nitrogen Applied).

Then, the nitrogen value obtained from the analysis of compost based on plant residues was taken, which has 2.73% (Table 5) (INIA, 2023c). This value was projected for doses of 6 to 8 t/ha, which resulted in 163.8 to 218.4 kg of nitrogen in compost.

Finally, by subtracting the amount of nitrogen obtained from the fertilization recommendation with the nitrogen present in the soil (180 kg/ha of N - 27.44 kg/ha of N), a surplus of 152.56 kg/ha of N was obtained. This surplus was compared with the nitrogen projected in the compost doses of 6 to 8 t/ha, which is equivalent to 163.8 to 218.4 kg/ha. Therefore, it was established that the standard dose is 6 t/ha of compost based on plant residues (peas).

2.9. Statistical processing

2.9.1. Statistical analysis of physical characteristics

a) Analysis of variance

Once the data on the physical characteristics of the radish were obtained, they were processed by analysis of variance, which determined whether the calculated F was greater than the tabulated F at 5% error (Fcal > Ftab5% error) or not, which means that there was significance (compost dose effect) or not. It is worth mentioning that the tabulated F values were obtained from Fisher's table at 5% error.

b) Duncan's test

After processing the data of the physical characteristics of the radish by means of the analysis of variance, the Duncan test at 5% error was performed, which qualified

Table 1. Dosage of compost based on plant residues per treatment.

Treatments	t/ha	g/plant
T_1	0	0
T_2	4	10
T_3	6	15
T_4	8	20
T_5	10	25

Table 2. Soil analysis of the radish experimental area.

E.C. 1:2.5 mS/cm	pH1:2.5	O.M. %	N %	P mg kg^{-1}	K mg kg^{-1}	$CaCO_{3\%}$	Cation Exchange (mEq/100 g soil)				CEC
							Ca	Mg	Na	K	
0.228	8.31	1.42	0.07	14.25	241.37	1.81	6.36	0.71	0.29	0.62	7.98

E.C.: Electrical conductivity; O.M.: Organic matter; CEC: Cation Exchange Capacity.
Source: INIA (2023a).

the averages and grouped them into a letter that indicates whether there is homogeneity or not. It also determined which dose stood out in relation to the others.

2.9.2. Statistical processing of total nitrogen input

In determining the amount of nitrogen for each treatment, a simple rule of three was used, which consisted of projecting 2.73 kg of nitrogen per 100 kg of compost at 4, 6, 8 and 10 t/ha of compost. The results were 109.2, 163.8, 218.4 and 273 kg/ha of nitrogen, respectively. These values were then added to the 27.44 kg of nitrogen in the soil for each treatment, thus obtaining the total nitrogen contribution. In this way, it was determined which total amount of nitrogen is related to the highest radish yield (See Table 6).

Table 3. Total to available nitrogen conversion factor in ppm in ratio (C/N).

Margin C/N ratio	Conversion factor from total nitrogen (T.N.) in percent, to nitrogen in ppm.
Greater than 12	11.2
10 to 12	140
Less than 12	225

Source: Kass (1998).

Table 4. Macronutrient recommendation for radish cultivation.

Nutrients (kg/ha)		
N	P_2O_5	K_2O
180	80	60

Source: INIA (2023b).

2.9.3. Statistical processing of stomata quantification

Regarding the quantification of stomata shown in Table 7, radish leaves from each treatment were sampled and observed by scanning electron microscopy at 300 µm (micrometers). Then, this measurement was projected on each side of the lens in millimeters and the length was multiplied by the width to obtain the area of 0.3228 mm². From there, the stomata of each treatment were counted and divided by the area of the lens. This process was performed for all treatments and was related to the highest radish yield. The Formula 4 is detailed below.

$$De \quad \frac{Ne}{Al.} \qquad (4)$$

where: De = Density of stomata; Ne = Number of stomata; Al. = Lens area (0.3228 mm²).

2.10. Data collection techniques

For the collection of data on the physical characteristics of radish, such as total length of the plant, weight of a plant, equatorial diameter of the bulb and commercial yield, observation techniques and statistical methods were used for data processing, which determined reliable results. According to Argüelles-Pascual et al. (2021), they mention that in the statistical method a series of steps are carried out in order to obtain reliable results of the subject under investigation and thus avoid obtaining erroneous conclusions. As for the instruments, precision materials such as digital balance, ruler and vernier were used. In addition, in the biological analysis, the Quanta model scanning electron microscope was used to determine the density of stomata and in the chemical analysis, materials from the INIA - Huaral laboratory and AGQ Perú SAC were used.

Table 5. Results of the chemical analysis of the compost.

ID Sample	pH	E.C. mS/cm	Humidity (%)	O.M. (%)	N (%)	P_2O_5 (%)	K_2O (%)	CaO (%)	MgO (%)	C/N
Compost	8.14	3.56	6.45	53.56	2.73	3.02	3.69	8.93	1.11	11.38

Source: INIA (2023c).

Table 6. Total nitrogen contribution of radish yield.

Treatment	Compost dosage (t/ha)	Amount of nitrogen in soil (kg/ha)	Amount of nitrogen in compost (kg/ha)	Total nitrogen input (kg/ha)	Commercial yield (t/ha)
T_1	0	27.44	0	27.44	15.460
T_2	4	27.44	109.2	136.64	19.187
T_3	6	27.44	163.8	191.24	20.013
T_4	8	27.44	218.4	245.84	21.947
T_5	10	27.44	273.0	300.44	22.530

Note: Compost has 2.73% nitrogen (Table 5). Projected at 10 t/ha it has 273 kg/ha of nitrogen.

Table 7. Stomata density in radish leaves by treatment.

	T_1	T_2	T_3	T_4	T_5
Number of stomata (0.3228 mm², lens area)	60	132	153	172	193
Stomatal density (number of stomata/mm²)	185.9	408.9	474.0	532.8	597.9
Stomatal index %	37.50	40.00	44.09	48.45	52.73
Number of cells (0.3228 mm²)	160.0	330.0	347.0	355.0	366.0

Note: Projected lens area is equivalent to 0.3228 mm².

2.11. Methodological techniques for soil nutrient determination

A soil sample was taken to the laboratory of INIA - Huaral. There, techniques were used to determine pH using method 9045D for soils and residues. For organic matter, Walkley and Black's AS-07 method was used. Nitrogen (N) was calculated from the data obtained for organic matter. Phosphorus (P) was calculated using the method of Olsen and collaborators. Potassium (K) was determined using Calcium Carbonate determination techniques (Method AS-29 acid neutralization) and for the Exchangeable Cations (Ca, Mg, Na, K) the Cation Exchange Capacity and the Exchangeable Bases of the soil were determined with ammonium acetate.

2.12. Procedures

Compost was made from 60 kg of dry pea grass and 40 kg of cattle guano and covered with a blanket. This material was then removed with a lampa and at that time 4 to 5 liters of water were added each week. This process continued for a period of 120 days or 4 months, until the compost reached a fluffy condition, dark in color and without unpleasant odor.

After soil preparation in the conventional way or as done by farmers in the area of the Supe Puerto district, province of Barranca, Lima, soil samples were taken using the zigzag technique at a depth of 0.25 meters. Subsequently, the samples were piled and removed and finally 1 kg of soil was extracted and taken to the INIA-Huaral laboratory.

Continuously after setting up and implementing the experiment area, the statistical model of Completely Randomized Block Design was employed, which consisted of 3 blocks and 5 treatments. The treatment area is stated to be 1.6 m long, 1 m wide and comprises 2 twin furrows at 0.5 m distance.

Then, radish seeds were broadcast sown on October 14, 2023. After 7 days, the plants were removed, leaving a distance of 0.10 meters between each plant and 14 days after sowing, the dose of compost based on vegetable waste (peas) was applied once, as shown in Table 1.

Evaluations were conducted until harvest, which was on November 14, 2023. During this period, data were collected on radish physical characteristics such as plant length, plant weight, bulb equatorial diameter and marketable yield.

Once these data were obtained, they were processed by analysis of variance and Duncan's test, which determined if there was a dose effect and which treatment stood out in comparison with the others.

Subsequently, 200 g of leaf samples were taken from each treatment and taken to the AGQ Peru SAC laboratory, where the concentration of nutrients that influenced yield was determined. The stomata were also observed using a Quanta scanning electron microscope and stomata density was quantified.

Finally, yield and cost projections were made for each treatment per hectare. This resulted in the cost of production and the commercial yield. The commercial yield was multiplied by the value of the price per unit of radish, which resulted in the total income. This amount was then subtracted from the cost of production to obtain the profit. With these values the profitability was determined, for which the following Formula 5 was applied.

$$P. = \frac{U}{Cp} * 100 \tag{5}$$

where: P.: Profitability; U.: Utility; C.P.: Cost of production.

3. Results

3.1. Soil analysis of the experiment area and recommendation

The results of the soil analysis determined that the pH is medium alkaline and high in phosphorus and potassium, but low in organic matter and nitrogen, according to the margins established by Prialé (2016). As for the Cation Exchange Capacity (CEC) is low, the exchangeable elements present medium concentration of calcium, magnesium and sodium, but high in potassium according to the values of McKean (1993). Therefore, the soil analysis indicates that this soil is suitable for planting radish; however, it is necessary to incorporate organic matter to improve soil properties and, therefore, increase yields (See Table 2) (INIA, 2023a).

After the soil analysis, the fertilization recommendation of 180 kg/ha of nitrogen necessary for the production of the radish crop was determined (See Table 4) (INIA, 2023b). In addition, it is important to mention that this amount of nitrogen was taken into account when establishing the standard dose of compost.

3.2. Concentration of nutrients in compost

The compost analyzed in the laboratory of INIA - Huaral, detailed in Table 5 (INIA, 2023c), showed a low concentration of organic matter, nitrogen, phosphorus and potassium. However, the carbon/nitrogen ratio has a value of 13.8. This result means that the compost has an adequate concentration of nutrients and C/N ratio, which means that the compost is mature and within the appropriate parameters. According to Iglesias Jiménez and Perez Garcia (1989), they mention that the optimum value for a mature compost varies in the C/N ratio from 11 to 13 and should have the necessary conditions of darkness to ensure a good homogenization of the material.

In relation to the analysis of microelements of the compost detailed in Table 8 (INIA, 2023d), it is observed that it presents high concentration of iron, zinc and copper compared to the study conducted by Toledo (2016), which states that the levels of suitable elements, such as iron, are between 56 and 112 ppm, copper and zinc between 1.7 and 3.4 ppm.

3.3. Physical characteristics of radish

After the statistical analysis, it was determined that in the physical characteristics of the radish, T_5 with 10 t/ha stood out; however, statistically there was no significance. Therefore, it is interpreted that the higher the dose of compost, there was no effect of compost dose, but it stood out in yield and quality with respect to the other treatments (See Table 9).

3.4. Total nitrogen input per treatment

With respect to the total nitrogen contribution detailed in Table 6, it is indicated that the highest dose of compost, which is T_5 with 10 t/ha, contributed the greatest amount of nitrogen with 300.44 kg/ha. Therefore, it is interpreted that at this amount of nitrogen, there was greater nutritional availability, which influenced the higher yield in relation to the other treatments.

3.5. Nutrient concentration of radish leaves

Analyzing the chemical characteristics in the radish leaves, it was determined that T_3 stood out in most of the elements, such as nitrogen, potassium, phosphorus and magnesium. However, these amounts did not influence yield. Therefore, it is interpreted that T_5, which has adequate concentration of nutrients such as magnesium, manganese and zinc according to the values of Legua Cárdenas et al. (2023), had higher yield and better bulb quality (See Table 10) (AGQ Peru SAC, 2023).

3.6. Quantification of stomata by treatment

Regarding the biological analysis, specifically the density of stomata, it was determined that T_5, with 598 stomata/ mm^2, differed by 69% with respect to T_1 with 186 stomata/ mm^2. This result is interpreted that increasing the doses of compost based on plant residues influenced the increase in stomata and, at the same time, the optimal biochemical reactions, which resulted in higher yields compared to the other treatments (See Table 7 and Figure 1).

3.7. Economic profitability analysis

Regarding the profitability analysis, it was determined that T_5, with 186.8%, differs by 18.09% with respect to T_1, which has 153%. These results can be interpreted as follows: the highest dose (10 t/ha of compost) obtained 18% more compared to the control and a profit of 87% more than that invested, which indicates that it is profitable (See Table 11).

4. Discussion

4.1. Physical characteristics of radish

By analyzing the physical characteristics data using analysis of variance and Duncan's test, it was determined that dose had no effect. However, the T5 treatment was superior in total plant length, plant weight, equatorial bulb

Table 8. Analysis of microelements in the compost.

Items	Fe	Zn	Cu	Mn
Quantity (mg kg^{-1})	692.0	93.50	12.50	265.0

Note: (mg kg^{-1}) equal to ppm (Parts per million).
Source: INIA (2023d).

Table 9. Physical characteristics of radish according to the compost doses.

Treatment	Compost dosage (t/ha)	Total plant length (cm)	Weight of a plant (g)	Equatorial bulb diameter (cm)	Commercial yield (t/ha)
T_5	10	28.077 a	75.00 a	4.52 a	22.530 a
T_4	8	27.220 a	70.88 a	4.30 a	21.947 a
T_3	6	26.740 a	67.00 a	4.22 a	20.013 a
T_2	4	26.380 a	57.25 a	3.84 a	19.187 a
T_1	0	25.893 a	55.83 a	3.80 a	15.460 a
Variation coefficient (%)		10.69	29.97	11.92	36.38
Significance		N.S.	N.S.	N.S.	N.S.

Note: (S) means significance, (N. S.) non-significance and (a) score obtained by Duncan's test. When the letters are the same, they represent homogeneity.

Table 10. Nutrient concentration in radish leaves by treatment.

Items	T_1	T_2	T_3	T_4	T_5	Normal range according to Legua Cárdenas et al. (2023)
Macronutrients (%)						
Total Nitrogen	4.2	4.0	4.2	4.0	3.8	4.75-5.50
Potassium	1.21	1.10	1.23	1.15	1.14	2.00-6.00
Phosphorus	0.264	0.261	0.268	0.242	0.250	0.45-1.10
Calcium	4.73	5.11	4.77	4.86	5.03	0.50-1.50
Magnesium	0.565	0.539	0.562	0.656	0.608	0.25-1.00
Sulfur	0.62	0.68	0.75	0.63	0.59	
Micronutrients (mg kg^{-1})						
Molybdenum	3.26	2.37	2.39	2.85	2.29	
Iron	223	191	206	195	158	60-140
Manganese	155	161	142	171	168	26-360
Copper	6.22	5.23	5.97	6.39	4.68	5.00-15.0
Zinc	66.2	54.5	62.4	65.9	58.9	10.0-80.0
Boron	48.9	48.5	48.9	50.0	46.7	
Phytotoxic elements (%)						
Chlorides	4.29	4.75	4.87	4.30	4.29	
Sodium	1.40	1.62	1.36	1.50	1.64	

Source: AGQ Perú SAC (2023).

Table 11. Profitability and cost-benefit economic analysis.

Treatment	Compost dosage (t/ha)	Commercial yield (kg/ha)	Unit value ($)	Total income ($)	Cost of production ($)	Utility ($)	Profitability (%)
T_1	0	15460	0.32	4973.73	1965.7	3008.02	153.0
T_2	4	19187	0.32	6172.76	2306.1	3866.68	167.7
T_3	6	20013	0.32	6438.50	2355.6	4082.87	173.3
T_4	8	21947	0.32	7060.70	2485.6	4575.09	184.1
T_5	10	22530	0.32	7248.26	2527.1	4721.15	186.8

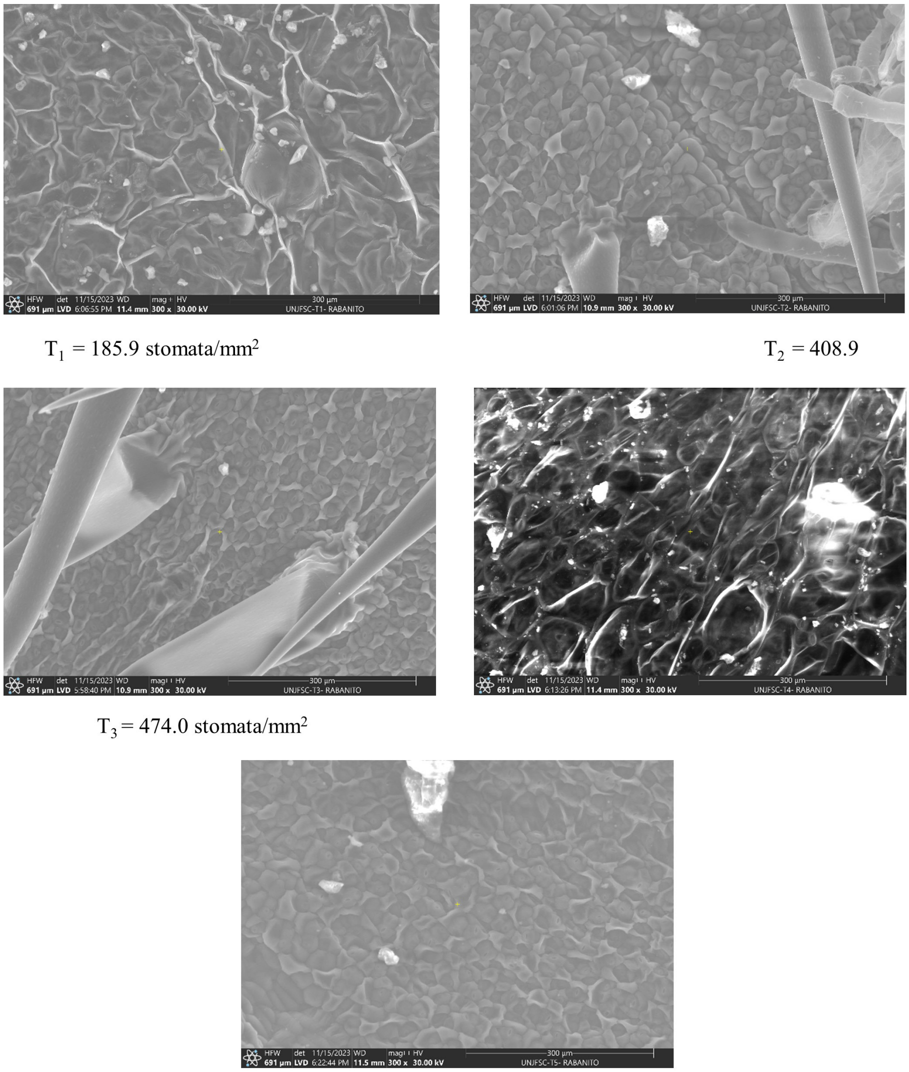
diameter and commercial yield of radish (See Table 9). It was determined that higher compost doses contributed more nutrients such as N, P, K and microelements to the soil, increasing their availability for plant absorption. This resulted in favorable responses in bulb development, yield and quality. These results are coincident with the research by Cruz Nieto et al. (2022), who determined that, at appropriate doses, T4 with 8 t/ha of compost based of market residues increased nutrient concentration and stomatal density in plant leaves, resulting in a higher yield of 10.82 t/ha of radish, a 20.51% increase compared to T1 with 8.60 t/ha.

4.2. Total nitrogen input in relation to yield

Regarding the total nitrogen supply per treatment indicated in Table 6, it was determined that at the highest dose (T_5), 300.44 kg of nitrogen were available, and that this amount influenced the highest radish yield with 22.530 t/ha. Therefore, it is analyzed that the higher the dose of compost incorporated into the soil, the greater the availability of nitrogen and other elements in the soil, and this amount favored greater absorption by the plant, which influenced the good development and strengthening against environmental stress and pests, obtaining higher yields and bulb quality. This analysis is supported by Castañeda Chirre et al. (2022), who determined that the concentration of total nitrogen stood out in T_5, with 194.44 kg/ha of total nitrogen use, obtaining a higher radish yield of 12.051 t/ha.

4.3. Nutrient concentrations in radish leaves

In relation to the chemical analysis of the radish leaves detailed in Table 10, it was specified that T_3 stood out



T_1 = 185.9 stomata/mm²

T_2 = 408.9

T_3 = 474.0 stomata/mm²

T_5 = 597.9 stomata/mm²

Figure 1. Micrograph of stomata of radish leaves by treatment.

in most of the elements, such as nitrogen, potassium, phosphorus and magnesium. However, these amounts of these elements did not influence yield, since T_5 excelled with 22.530 t/ha of radish. Therefore, it is analyzed that T_5, which has an adequate concentration of nutrients such as magnesium, manganese and zinc according to the values of Legua Cárdenas et al. (2023), had response in good development and strengthening, which resulted with higher yield and bulb quality. The increase in calcium and magnesium, which influenced the decrease in potassium, is also noteworthy. In this regard, Torri (2005) mentions that as the leaf matures, an increase in Ca and Mg is observed and a reduction in the concentration of N and P. This is due to the fact that in the bulb filling stage, calcium concentration accumulates and K concentration decreases (it intervenes in carbohydrate and protein metabolism processes). Rodríguez and Flórez (2004) mention that calcium (Ca^{2+}) forms calcium pectates that provide consistency and a certain degree of rigidity to the cell wall and in the cell walls protect the tissues against fungal attack.

4.4. Quantification of stomata per treatment

Regarding the quantification of stomata per treatment detailed in Table 7 and Figure 1, it was determined that T_5 with 597.9 stomata/mm^2 stood out with respect to the other treatments. This result analyzes that by increasing the doses of compost based on plant residues, nutrients were added to the soil such as N, P, K and other elements that promoted the increase of stomata and that this amount optimized the function of gas exchange, evapotranspiration and other reactions. The aforementioned is supported by Fernandez et al. (2015) mention that stomata are pores surrounded by two guard cells that regulate their opening and closing; they are present in high densities in leaves and are responsible for the control of gas exchange and transpiration of the plant. Li et al. (2022) stomata play important roles in gas and water exchange in leaves. It should also be noted that at this dose, nutrients such as K were added, which at this concentration was involved in important biochemical functions such as gas exchange, evapotranspiration and other biochemical reactions for carbohydrate formation, thus obtaining higher yields. Larriva (2006) mentions that potassium accumulates early in the growth period and then is distributed to intervene in photosynthesis, regulating the opening of the stomata, allowing the assimilation of CO_2 and the exit of O_2, maintaining a good water ratio in the plant by reducing evapotranspiration.

4.5. Economic profitability analysis

Regarding the economic analysis of profitability, detailed in Table 11, it is highlighted that T_5, with 186.8%, differs by 18.09% with respect to T_1, which has 153%. Therefore, it is analyzed that at a higher dose (10 t/ha of compost), a greater gain of 18% was obtained compared to the control and 87% more of what was invested. This result is favorable for farmers when planting radishes in the district of Supe Puerto.

5. Conclusion

It was concluded that the highest dose, which is T_5 with 10 t/ha of compost based on vegetable residues, stood out in commercial yield with 22.53 t/ha, which differed by 31.38% in relation to T_1 with 15.46 t/ha of radish. Therefore, this result shows that by applying this amount of compost to the soil, nutrients were added, which resulted in adequate nutrient concentrations and higher density of stomata in leaves. This influenced the optimal biochemical reactions, resulting in good development, strengthening and, therefore, higher yield and quality of the bulb.

It was also noted that in the chemical analysis of radish leaves, T_3 stood out with nitrogen, potassium, phosphorus and magnesium. However, T_5 with adequate concentrations of magnesium, manganese and zinc obtained higher radish yields. Therefore, these concentrations of nutrients in leaves optimized the formation, translocation of carbohydrates and other biochemical reactions that resulted in higher yield and bulb quality.

Finally, in the analysis of stomata, it was determined that the higher the compost dose, which is T_5, the higher the density with 598 stomata/mm^2. Therefore, this quantity is established as an indicator that influenced the optimal reactions of evapotranspiration, formation, translocation of carbohydrates and other biochemical reactions that had a response in the good development, strengthening and, therefore, higher yield and quality of radish bulb.

References

AGQ PERÚ, S.A.C., 2023. *Informe de ensayo-material vegetal. Acreditado IAS, Testing Laboratory TL-502. Códigos V-23/069273, V-23/069274, V-23/069275, V-23/069276, V-23/069277*. Lima: AGQ LABS.

ARCE-INSUASTY, K., BENAVIDES, M., ACOSTA, J. and ÁLVAREZ, D., 2019 [viewed 27 April 2024]. Evaluación de los subproductos del cultivo de arveja (*Pisum sativum* L.) en la obtención de abono orgánico tipo Bocashi. In: *Encuentro Internacional de Educación en Ingeniería* [online], 2019, Cartagena de Indias, Colombia. Bogotá, D.C.: Asociación Colombiana de Facultades de Ingeniería, pp. 1-9. Available from: https://acofipapers.org/index.php/eiei/article/view/203/196

ARGOTE, V.A., 2016. *Determinación del efecto del compost de la paja de arroz como enmienda húmica en el cultivo de frijol (Phaseolus vulgaris L.) Var. Canario 2000 en los suelos del Valle de Camaná - Arequipa 2014*. Perú: Universidad Católica de Santa María, 98 p. Tesis para Optar el Título Profesional de Ingeniero Agrónomo.

ARGÜELLES-PASCUAL, V., BURGOS-MARTÍNEZ, R. and H. PALACIOS, R., 2021. Etapas del método estadístico. *Ciencia Huasteca Boletín Científico de la Escuela Superior de Huejutla*, vol. 9, no. 17, pp. 35-36. http://doi.org/10.29057/esh.v9i17.6703.

CAJUSOL, F.D. and MOISUPE, L.A., 2019. *Caracterización físico-química y biológica del compost obtenido con residuos sólidos agropecuarios en Lambayeque, septiembre a diciembre de 2016*. Perú: Universidad Nacional Pedro Ruiz Gallo, 50 p. Tesis de Licenciado en Biología Microbiología - Parasitología.

CARDONA, S. and HERNÁNDEZ, L.J., 2008. *Aprovechamiento de residuos de podas mediante compostaje en la escuela Militar de Aviación "Marco Fidel Suárez"*. Colombia: Universidad Autónoma de Occidente, 117 p. Pasantía para al Título de Administradoras Ambientales.

CASTAÑEDA CHIRRE, E.T., NUNJA GARCÍA, J.V., SÁNCHEZ GUZMÁN, A.I., SAUCEDO LÓPEZ, M.C., RUIZ SÁNCHEZ, B.B., CASTRO BARTOLOMÉ, H.J. and MUGURUZA CRISPIN, N.E., 2022. Sostenibilidad con compost a base de residuos de mercado para obtener mayor rendimiento de rabanito (*Raphanus sativus* L.), Barranca. *Revista Alfa*, vol. 6, no. 18, pp. 567-580. http://doi.org/10.33996/revistaalfa.v6i18.192.

CRUZ NIETO, D.D., RODRIGUEZ, R.F., LEGUA, J.A., NATIVIDAD, D.E., IPANAQUÉ, J.M., ABARCA, J.J. and RAMOS, R.L., 2022. 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. *Chemical Engineering Transactions*, vol. 94, pp. 1387-1392. http://doi.org/10.3303/CET2294231.

FERNÁNDEZ, V., SOTIROPOULOS, T. and BROWN, P., 2015 [viewed 19 January 2024]. *Fertilización foliar: principios científicos y práctica de campo* [online]. 1ª ed. Francia: Asociación Internacional de la Industria de Fertilizantes. Available from: https://www.guiaverde.com/files/company/03032016122136_libro_2015_foliar_fertilizers_spanish_def.pdf

HIRZEL, J. and SALAZAR, F., 2016 [viewed 12 December 2023]. *Guía de manejo y buenas prácticas de aplicación de enmiendas orgánicas en agricultura* [online]. Chile: INIA, Ministerio de Agricultura. Boletín INIA, no. 325. Available from: https://n9.cl/0n2kw

IGLESIAS JIMÉNEZ, E. and PEREZ GARCIA, V., 1989. Evaluation of city refuse compost maturity: a review. *Biological Wastes*, vol. 27, no. 2, pp. 115-142. http://doi.org/10.1016/0269-7483(89)90039-6.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2023a. *Análisis de suelo: resultados de análisis de suelo*. Perú: INIA, no. 09305-23/SU/ LABSAF - DONOSO.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2023b. *Recomendación nutricional para rabanito: resultados nutricional*. Perú: INIA, no. SU422-DO-23.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2023c. *Análisis de compost: resultados de característica química del abono*. Perú: INIA, no. 09362-23/AO/ LABSAF – DONOSO.

INSTITUTO NACIONAL DE INNOVACIÓN AGRARIA – INIA, 2023d. *Análisis de micro elementos del compost: resultados de micronutrientes del abono*. Perú: INIA, no. 09362-23/AO/LABSAF – DONOSO.

IPANAQUÉ, J., 2023. *Fertilización con compost producido de residuos sólidos orgánicos del mercado para mayor rendimiento en cultivo de vainita (Phaseolus vulgaris L.), Huaura – 2022*. Perú: Universidad Nacional José Faustino Sánchez Carrión, 69 p. Tesis para el Grado Académico de Doctor en Ciencias Ambientales.

KASS, C.L.D., 1998 [viewed 22 January 2024]. *Fertilidad de suelos* [online]. San José: EUNED. Available from: https://books.google.com.pe/books?id=sRua411JhvgC&pg=PP8&dq=KASS+FERTILIDAD+DE+SUELOS&hl=es&sa=X&ved=2ahUKEwiQ_p2Tx_r0AhU_qZUCHcNUAwQQ6AF6BAgHEAI#v=onepage&q=KASS%20FERTILIDAD%20DE%20SUELOS&f=false

LARRIVA, N., 2006 [viewed 21 January 2024]. Síntesis de la importancia del Potasio en el suelo y plantas. *La Granja Revista de Ciencias de La Vida* [online], vol. 2, no. 1, pp. 23-24. Available from: https://lagranja.ups.edu.ec/index.php/granja/article/view/2.2003.09

LEGUA CÁRDENAS, J.A., CAMPOS DIAZ, A.H., VÉLEZ CHANG, D.J. and VÉLEZ CHANG, Y.J., 2023. Efectos del biol industrial complementado con algas marinas sobre el rendimiento del cultivo rábano (*Raphanus sativus* L.). *Revista Alfa*, vol. 7, no. 20, pp. 442-452. http://doi.org/10.33996/revistaalfa.v7i20.227.

LI, S., LI, L., FAN, W., MA, S., ZHANG, C., KIM, J.C., WANG, K., RUSSINOVA, E., ZHU, Y. and ZHOU, Y., 2022. LeafNet: a tool for segmenting and quantifying stomata and pavement cells. *The Plant Cell*, vol. 34, no. 4, pp. 1171-1188. http://doi.org/10.1093/plcell/koac021. PMid:35080620.

MCKEAN, S., 1993 [viewed 20 January 2024]. *Manual de análisis de suelos y tejido vegetal. Una guía teórica y práctica de metodologías* [online]. Panama: Laboratorio de Servicios Analíticos, Centro Internacional de Agricultura Tropical (CIAT), Documento de trabajo, no. 129. Available from: http://ciat-library.ciat.cgiar.org/Articulos_Ciat/Digital/S593.M2_Manual_de_an%C3%A1lisis_de_suelos_y_tejido_vegetal_Una_gu%C3%ADa_te%C3%B3rica_y_pr%C3%A1ctica_de_metodologia.pdf

PÉREZ LEAL, F., 2017 [viewed 16 January 2024]. *Fisiología vegetal. Parte III: nutrición mineral* [online]. Perú: Facultad de Ciencias Agropecuarias, Universidad Nacional de Ucayali. Available from: http://repositorio.unu.edu.pe/bitstream/handle/UNU/3201/000026082L.pdf

PRIALÉ, C.A., 2016 [viewed 26 December 2023]. *Muestreo de suelos: referencias sobre el análisis e interpretación de resultados* [online]. Peru: INIA. Available from: https://repositorio.inia.gob.pe/bitstream/20.500.12955/286/1/Muestreo_de_suelos.pdf

RODRÍGUEZ, M. and FLÓREZ, V., 2004 [viewed 18 January 2024]. *Elementos esenciales y beneficiosos* [online]. Colombia: Facultad de Agronomía, Universidad Nacional de Colombia. Available from: https://repositorio.ual.es/bitstream/handle/10835/3133/F13.pdf?sequence=1&isAllowed=y

TOLEDO, M., 2016 [viewed 22 December 2023]. *Manejo de suelos ácidos de las zonas altas de Honduras: conceptos y métodos* [online]. 1ª ed. Honduras: Dirección de Ciencia y Tecnología Agropecuaria, Instituto Interamericano de Cooperación para la Agricultura, 145 p. Available from: https://repositorio.iica.int/bitstream/handle/11324/3108/BVE17069071e.pdf;jsessionid=8636C4F0181DC9

TORRI, S., 2005 [viewed 26 December 2023]. *Análisis foliar* [online]. Argentina: Facultad de Agronomía, Universidad de Buenos Aires. Publications, no. 56. Available from: https://www.researchgate.net/profile/Silvana-Torri/publication/305849363_Analisis_foliar/links/57a378f208ae455e85306f89/Analisis-foliar.pdf

VELA, G., LÓPEZ, J. and RODRÍGUEZ, M., 2012. Levels of total organic carbon in the Suelo de Conservación of the Distrito Federal, Central Mexico. *Investigaciones Geográficas*, no. 77, pp. 18-30. http://doi.org/10.14350/rig.31007.