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# Use of Compost in Onion Cultivation under No-Tillage System: Effect on Nutrient Uptake

Fábio Satoshi Higashikawa[a], Rafael Ricardo Cantú[b], Keiji Jindo[c], Claudinei Kurtz[a], Paulo Antônio de Souza Gonçalves[a], and João Vieira Neto[a]

[a]Agricultural Experiment Station of Ituporanga, Agricultural Research and Rural Extension Company of the State of Santa Catarina - Epagri, Ituporanga, Brazil; [b]Agricultural Experiment Station of Itajaí, Agricultural Research and Rural Extension Company of the State of Santa Catarina – Epagri, Itajaí, Brazil; [c]Agrosystems Research, Wageningen University & Research, Wageningen, The Netherland

**ABSTRACT**

The nutrition of onion grown in a no-tillage system with compost requires research to provide alternatives to mineral fertilizers. Our objective was to evaluate the effect of compost rates on the nutrient content in the tissue of onion grown in a no-tillage system. We conducted a field experiment with the following treatments: 0, 10, 20, 30, and 60 Mg ha$^{-1}$ of compost and mineral fertilization. We applied these treatments in 2018, 2019, and 2020 for onion cultivation. We used a 3 × 6 factorial scheme (year x treatment) and four replications. We evaluated the bulbs and whole plant nutrient contents of N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, and B. In 2020, nutrient content in the bulb from 10 Mg ha$^{-1}$ of compost was similar to the mineral fertilizer's treatment. Therefore, compost can replace mineral fertilizers to supply nutrients to the onion. However, the continuous application of compost requires soil monitoring due to nutrient accumulation.

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Allium cepa L.; no-tillage; organic waste; plant nutrition

## Introduction

Onion is an important crop, and its world production in 2020 was more than 104 million megagrams and was the fourth most produced vegetable in the world after potato, cassava, and tomato (FAO 2020). In Brazil, onion was the fourth most cultivated vegetable in 2020, after cassava, potato, and tomato (IBGE 2022). Brazil imported more than 80% of fertilizers in 2021 (ANDA 2022), and reducing this external dependence is extremely important to increase the competitiveness of Brazilian agriculture in the international market (Brasil 2021) and promote the autonomy of production for domestic consumption. One of the ways to reduce the use of mineral fertilizers is using alternative local sources such as compost and manures. The management of organic waste through recycling in agriculture is a promising alternative (Provenzano et al. 2001).

The safe disposal of organic waste in agriculture requires proper characterization to analyze its potential for agricultural use (Silva 2008). Organic fertilizers and soil conditioners to be used in agriculture must present pathogens and heavy metals following the limits of the legislation (MAPA 2006). However, characterization is just one step in the use of organic waste, as it is necessary to consider current legislation, continuous monitoring of the application of these materials, and evaluate the effects of applied waste on the environment, crop production, and the harvested product (Higashikawa, Silva, and Bettiol 2010). Regarding organic waste, in addition to following technical criteria, materials available locally or regionally must be used, as transport can be an economic

**CONTACT** Keiji Jindo keiji.jindo@wur.nl Agrosystems Research, Wageningen University & Research, Wageningen, The Netherland

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limitation (Higashikawa and Kurtz 2016). In addition, the imbalance and variability of nutrients regarding plant requirements (Westerman and Bicudo 2005), as well as other attributes, whether chemical or physical, can limit the agricultural use of organic residues for organic fertilization. Regarding the compost applications, it is necessary to know more deeply about the rates of nutrient availability and its residual effects and the challenge of meeting the nutritional demand of plants (Cantú et al. 2019). In Santa Catarina State, most onion cultivation is done in a conventional soil tillage system with fertilization restricted to mineral sources (EPAGRI 2013). Conversely, the cultivation of onions in the no-tillage system is recommended due to the protection and improvement of the soil's physical, chemical, and biological quality provided by the cover crops (Comin et al. 2018) and the increase in yield (Oliveira et al. 2016). Little studies have been explored the effect of the compost application on the onion growth under the no-tillage system.

This work aimed to evaluate the effect of compost rates compared to mineral fertilizer on nutrient uptake by onion grown in a no-tillage system.

## Materials and methods

### *Experimental area*

The experiment was conducted at the Epagri Experimental Station in Ituporanga, Santa Catarina State, Brazil, located at 27º25'S, 49º38'W, 475 m. The region's climate was classified as Cfa according to the Köppen classification (Alvares et al. 2013). According to Santos et al. (2013), the soil under study was classified as Humic Cambisol. The State of Santa Catarina is the largest national producer of onions, with a share of 28% of onion production in Brazil (IBGE 2022). The Ituporanga region is the largest onion producer in Santa Catarina State, and the predominant soil in this region is Cambisol. This study is the continuity of the previous research (Higashikawa et al. 2022) that discussed the effect of treatments (0, 10, 20, 30, and 60 Mg ha$^{-1}$ of compost and mineral fertilization) on onion yield and soil fertility. The precipitation and maximum and minimum temperatures recorded during onion crops in 2018, 2019, and 2020 are shown in Figure 1 (EPAGRI 2020). In October 2019, there was a hailstorm during the onion bulbification period, which consequently reduced the yield of the bulbs (Table 1).

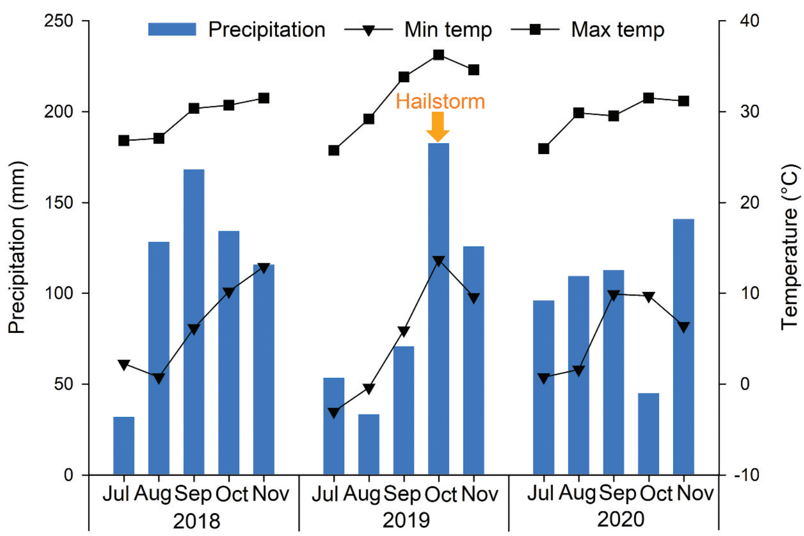


Figure 1. Climate data for July to November for 2018, 2019, and 2020.

**Table 1.** Year, season, cover crop species sown in intercropping, sowing density, average dry matter production, and average marketable yield of onions grown under the no-tillage system in 2018, 2019, and 2020 according to Higashikawa et al. (2022). Means followed by the same capital letters do not differentiate the years by the Scott-Knott mean test (p < .05). Means followed by the same lowercase letters do not differentiate treatments within each year by the Scott-Knott mean test (p < .05).

| Year | Season | Intercropped species | Sowing density (kg ha$^{-1}$) | Dry matter (Mg ha$^{-1}$) | Treatment | Marketable onion bulb yield (Mg ha$^{-1}$) |
|---|---|---|---|---|---|---|
| 2018 | Winter | *Avena strigosa Schreb* | 60 | | | |
| | | + | + | 8.78 | 0 | 39.91 Bb |
| | | *Raphanus sativus* | 10 | | 10 | 45.43 Ba |
| | | | (Oliveira et al. 2016) | | 20 | 45.20 Ba |
| | Summer | *Mucuna aterrima* | 40 | | 30 | 45.69 Ba |
| | | + | + | 9.34 | 60 | 45.94 Ba |
| | | *Pennisetum glaucum* | 30 | | MF | 47.97 Ba |
| | | | (MENEZES JÚNIOR et al., 2014) | | | |
| 2019 | Winter | *Secale cereale* L. | 60 | | 0 | 26.39 Ca |
| | | + | + | 8.66 | 10 | 21.62 Ca |
| | | *Raphanus sativus* | 10 | | 20 | 24.22 Ca |
| | | | (Oliveira et al. 2016) | | 30 | 25.75 Ca |
| | Summer | *Avena strigosa Schreb* | 40 | | 60 | 21.46 Ca |
| | | + | + | 11.24 | MF | 26.43 Ca |
| | | *Raphanus sativus* | 30 | | | |
| 2020 | Winter | *Avena strigosa Schreb* | 60 | | 0 | 43.41 Ab |
| | | + | + | 10.96 | 10 | 49.11 Aa |
| | | *Raphanus sativus* | 10 | | 20 | 49.11 Aa |
| | | | | | 30 | 49.38 Aa |
| | | | | | 60 | 49.44 Aa |
| | | | | | MF | 47.49 Aa |

The dry matter of the winter cover crops from 2019 and 2020 also considers the plant remains of the summer cover plants from the previous year. 0, 10, 20, 30, and 60 are rates of compost in Mg ha$^{-1}$ and MF = mineral fertilizer.

### *Field experiments*

The transplant of the onion seedlings cultivar SCS373 Valessul in 2018, 2019, and 2020 was performed in July, after flattening the winter cover plants using a knife roller (Table 1), which were sown in April. After harvest, summer cover plants were planted in December of each year, and the planting of winter cover plants was carried out on the straw of the summer cover plants. Cover crops were grown in consortium with two species in winter and summer, preceding each onion crop.

The treatments of the study were: mineral fertilization according to soil analysis and fertilization recommendations for onion culture (CQFS-RS/SC 2016) and rates of compost of 0, 10, 20, 30, and 60 Mg ha$^{-1}$, which were the rates used in the study by Vidigal et al. (2010). The compost used was elaborated from waste from pig breeding and slaughter, produced in the Lauro Pamplona composting plant in the municipality of Trombudo Central in Santa Catarina State. This compost has 62% of sludge from the effluent treatment station of the refrigeration units; 30% from sawdust that received liquid swine manure weekly for six months; 4% from residue from feed sweeps, and 4% from boiler ash. The compost was analyzed for levels of heavy metals and pathogens in government-accredited laboratories and met the limits considered safe for use in agriculture (MAPA 2006) according to the Brazilian Ministry of Agriculture, Livestock and Food Supply. The compost had macronutrient contents of 2.9% N; 2.0% of P; 0.8% of K; 0.5% of Ca and 0.05% of Mg, presenting micronutrient contents of 0.03% of Cu; 0.05% of Zn; 0.07% of Fe and 0.08% of Mn. The compost had 42.8% of total C and a C/N ratio of 14.7. The methodologies used to characterize the compost are described by Tedesco et al. (1995). To perform the chemical analyses, the compost samples were dried at 65°C until constant weight and then sifted in sieves with mesh smaller than 0.5 mm. To determine N, P, Ca, and Mg levels, digestion was performed with $H_2O_2$ and $H_2SO_4$. Nitrogen was determined by micro-Kjeldahl, P by spectrophotometry, K by flame photometry, and Ca and Mg by atomic absorption spectrophotometry. Perchloric nitric digestion was performed to determine Cu, Zn, Fe, and Mn. These micronutrients were determined by atomic absorption spectrophotometry.

The treatment with mineral fertilization (MF) received 150 kg $ha^{-1}$ of N by applying ammonium nitrate, 157.5 kg $ha^{-1}$ of $P_2O_5$ by simple superphosphate, and 127.5 kg $ha^{-1}$ of $K_2O$ provided by potassium chloride. Nitrogen rates from ammonium nitrate were applied at 15% at planting, 25% at 35 days after transplantation (DAT), 35% at 60 DAT, and 25% at 85 DAT, while 50% of the $K_2O$ (KCl) rate was applied in planting and the remainder at 60 and 85 DAT. The rates of compost were all applied when transplanting the onion seedlings and did not receive complementation of mineral fertilizers. Before the manual transplanting of seedlings, the surface application of mineral fertilizers or compost was made and distributed in the total area of the plots. The manual transplant of the onion seedlings in July of each year was performed after opening furrows with a micro tractor adapted to operate on straw. The spacing between plants was 40 cm between rows and 8 cm between them, which resulted in a density of 312,500 plants per hectare. The plot size was 9.6 $m^2$. The working area considered to evaluate onion yield was 6.1 $m^2$. The experimental design was randomized blocks with four replicates and six treatments (mineral fertilizer and rates of compost of 0, 10, 20, 30, and 60 Mg $ha^{-1}$). Each block consisted of six plots with a distance between plots of 1 m. The experiment consisted of four blocks of six treatments located side by side, thus totaling 24 plots in each agricultural year (2018, 2019, and 2020). For the passage of a tractor used in applying chemicals, the spacing in the middle of the four blocks was 2.5 m. However, the space between the two blocks on each side of the tractor pass was 1 m. Treatments were repeated each year in the same plots. Therefore, the experiment consisted of a factorial combination of years (2018, 2019, and 2020) and treatments (mineral fertilization and five rates of compost). Thus, the experimental scheme was a $3 \times 6$ factorial with four replications.

Weed, disease, and pest control were performed with chemicals registered for onion culture at the Brazilian Ministry of Agriculture. Three applications of the herbicides, clethodim and pendimethalin, and a manual weeding for weed control were carried out. Eight applications of fungicides with the active ingredients propineb, metalaxyl + chlorothalonil, and metalaxyl + mancozeb, were performed to control the fungal disease mildew (*Peronospora destructor*). In the management of the insect thrips (*Thrips tabaci* Lind.), three applications of insecticides with lambda-cyhalothrin and imidacloprid were performed. Both fungicides and insecticides were applied in alternating products with different modes of action and active ingredients in plants (contact and systemic). At the end of the year's experiment, the marketable onion bulb yield (Table 1) was evaluated. According to market standards, marketable onion bulbs have a transverse diameter equal to or greater than 35 mm and are without defects (MAPA 1995).

## Soil analysis

In April, soil samples from the 0 to 20 cm layer were collected 20 days before planting the green manure in the 2018 winter (Table 1). In each plot, after onion harvest in 2018, 2019, and 2020, subsamples were collected in five random points to comprise a soil sample of the layer from 0 to 10 cm (Table 2). The soil samples were air-dried and then sieved in a mesh smaller than 2 mm. The chemical analyses in the laboratory were conducted as follows (CQFS-RS/SC 2016): pH in soil-water suspension in the ratio of 1:1; Ca, Mg, Al, and Mn were extracted by KCl 1 mol $L^{-1}$; P, K, Cu, and Zn were extracted by the Mehlich-1 method; sulfate was extracted with calcium phosphate solution; B was extracted with hot water; the methodology used for organic matter (OM) was carbon oxidation by sulfochromic solution. By colorimetry, the contents of P, B, and OM; by photometry, the contents of K; by turbidimetry, sulfate contents; and by atomic absorption spectrophotometry, the contents of Ca, Mg, Cu, Zn, Fe, and Mn were determined. The granulometric analysis (Donagemma et al. 2017) to quantify the sand, silt, and clay fractions were made only before the installation of the experiment in 2018 in the layer from 0 to 20 cm. The separation of the fractions was made by sieving and

**Table 2.** Soil properties before the installation of the experiment in 2018 and after the onion harvest at the end of 2018, 2019, and 2020 according to Higashikawa et al. (2022). Soil properties after onion harvest are average values (n = 4).

| Treatment | Soil property | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Clay | Sand | Silt | pH | Ca | Mg | Al | $CEC_p$ | P (Melich-1) | K (Melich-1) | Sulfate | BS | OM | B | Cu | Zn | Fe | Mn |
| | g $kg^{-1}$ | | | | cmol$_c$ $dm^{-3}$ | | | | mg $dm^{-3}$ | | | % | % | | mg $dm^{-3}$ | | | |
| Before installing the experiment in 2018 | | | | | | | | | | | | | | | | | | |
| 0–20 cm | | | | | | | | | | | | | | | | | | |
| | 246 | 399 | 355 | 5.70 | 5.60 | 3.30 | 0.00 | 12.68 | 21.00 | 116.00 | 43.10 | 72.40 | 3.20 | 0.50 | 0.30 | 5.60 | 115.00 | 8.40 |
| After the onion harvest in 2018* | | | | | | | | | | | | | | | | | | |
| 0–10 cm | | | | | | | | | | | | | | | | | | |
| 0 | — | — | — | 5.90 | 5.27 | 3.32 | 0.00 | 12.85 | 16.37 | 209.13 | 51.27 | 64.82 | 2.52 | 0.54 | 0.77 | 5.82 | 160.50 | 12.55 |
| 10 | — | — | — | 6.07 | 5.30 | 3.40 | 0.00 | 13.76 | 43.35 | 219.10 | 50.67 | 67.11 | 3.02 | 0.54 | 1.30 | 11.21 | 130.50 | 9.27 |
| 20 | — | — | — | 5.85 | 5.45 | 3.15 | 0.00 | 14.17 | 112.12 | 328.30 | 57.80 | 64.07 | 3.52 | 0.55 | 2.72 | 27.50 | 110.75 | 14.80 |
| 30 | — | — | — | 6.05 | 5.42 | 3.35 | 0.00 | 13.82 | 94.86 | 292.80 | 54.00 | 71.83 | 3.05 | 0.55 | 2.34 | 24.77 | 114.25 | 15.50 |
| 60 | — | — | — | 5.97 | 6.10 | 3.45 | 0.00 | 15.27 | 251.23 | 419.84 | 64.70 | 69.81 | 3.97 | 0.64 | 4.00 | 49.27 | 111.75 | 17.82 |
| MF | — | — | — | 5.92 | 5.02 | 3.17 | 0.00 | 12.89 | 37.97 | 246.34 | 53.68 | 65.03 | 2.57 | 0.55 | 0.65 | 5.77 | 123.75 | 12.05 |
| After the onion harvest in 2019 | | | | | | | | | | | | | | | | | | |
| 0–10 cm | | | | | | | | | | | | | | | | | | |
| 0 | — | — | — | 5.90 | 6.55 | 4.40 | 0.00 | 16.36 | 16.02 | 238.95 | 40.60 | 70.69 | 3.02 | 0.77 | 1.37 | 6.36 | 85.00 | 3.30 |
| 10 | — | — | — | 6.01 | 6.25 | 4.41 | 0.00 | 14.58 | 39.15 | 287.45 | 43.62 | 70.40 | 2.70 | 0.75 | 1.47 | 14.65 | 90.25 | 6.00 |
| 20 | — | — | — | 5.95 | 7.90 | 4.45 | 0.00 | 18.01 | 91.47 | 344.52 | 47.45 | 73.45 | 3.32 | 1.23 | 2.12 | 29.73 | 88.75 | 6.52 |
| 30 | — | — | — | 6.02 | 6.77 | 4.32 | 0.00 | 16.22 | 148.11 | 349.35 | 52.77 | 73.82 | 3.47 | 0.87 | 2.52 | 35.77 | 85.00 | 5.40 |
| 60 | — | — | — | 6.07 | 9.07 | 4.60 | 0.00 | 19.44 | 365.39 | 559.00 | 57.73 | 77.59 | 4.17 | 1.28 | 3.72 | 92.28 | 115.25 | 9.15 |
| MF | — | — | — | 5.97 | 6.47 | 3.93 | 0.00 | 15.01 | 33.15 | 297.35 | 49.75 | 71.81 | 3.30 | 0.72 | 1.22 | 7.60 | 80.50 | 5.40 |
| After the onion harvest in 2020 | | | | | | | | | | | | | | | | | | |
| 0–10 cm | | | | | | | | | | | | | | | | | | |
| 0 | — | — | — | 5.90 | 5.60 | 3.55 | 0.00 | 12.87 | 11.12 | 187.58 | 46.62 | 74.51 | 3.07 | 0.62 | 0.85 | 7.92 | 140.87 | 3.45 |
| 10 | — | — | — | 6.15 | 6.55 | 3.92 | 0.00 | 14.11 | 57.52 | 213.00 | 41.15 | 78.07 | 3.85 | 0.72 | 1.32 | 26.07 | 96.00 | 4.40 |
| 20 | — | — | — | 6.00 | 6.54 | 3.57 | 0.00 | 14.49 | 131.55 | 304.50 | 53.50 | 71.96 | 4.55 | 0.81 | 1.92 | 39.00 | 85.25 | 4.09 |
| 30 | — | — | — | 6.07 | 7.15 | 3.55 | 0.00 | 15.11 | 198.38 | 330.00 | 46.17 | 76.45 | 4.65 | 0.77 | 2.02 | 55.40 | 80.25 | 5.67 |
| 60 | — | — | — | 6.00 | 7.58 | 3.37 | 0.00 | 17.00 | 322.18 | 550.80 | 54.27 | 75.41 | 5.90 | 1.17 | 2.82 | 101.50 | 78.25 | 7.22 |
| MF | — | — | — | 5.75 | 6.22 | 3.06 | 0.00 | 14.20 | 38.55 | 219.79 | 58.90 | 68.02 | 3.07 | 0.77 | 0.72 | 10.07 | 106.26 | 3.67 |

$CEC_p$ = potential cation exchange capacity. OM = organic matter. BS = base saturation. 0, 10, 20, 30 e 60 are rates of compost in Mg $ha^{-1}$ and MF = mineral fertilizer.

sedimentation, and the measurement of the fractions was separated by measuring with a densimeter the suspension density.

### Tissue analysis

Immediately after harvest, five plants from each plot were collected and washed with deionized water before dividing the shoot and bulb of each plant. The samples of the shoot and bulb were dried separately forced air circulation oven at 65ºC until they reached constant weight. Subsequently, the dried samples were ground in a mill with a 1 mm mesh sieve. After grinding, the samples were analyzed to determine the levels of N, P, K, Ca, Mg, S, Cu, Mn, Fe, and Zn. The N was determined by micro-Kjeldahl. Tissue samples (shoot and bulb) were submitted to perchloric nitric digestion to determine P and B per colorimetry, K by flame photometry, S by turbidimetry, and Ca, Mg, Cu, Fe, Mn, and Zn by atomic absorption spectrophotometry (Tedesco et al. 1995).

### Statistical analysis

Statistical analyses were performed in R language using software version 4.1.2 (R Core Team 2021). The nutrient uptake data (from the 2018 and 2020 harvest) by the bulb and the whole plant (shoot + bulb) were tested for normality and homogeneity through the car, nortest, dae, and MASS packages. These data were submitted to factor analysis (year and treatment factors), and the treatment means were compared by the Scott-Knott test ($p < .05$) through the ExpDes.pt. The 2019 data were not considered in the factor analysis due to a hailstorm (Figure 1), which affected the uptake of nutrients by the onion due to severe damage to the aerial part. Principal component analysis (PCA) of the nutrients uptake by the bulb and the whole plant was performed according to the treatments used (mineral fertilization and compost rates). The tidyverse, factoextra, FactoMineR, and ggpubr packages were used to make the PCA. Regression models were obtained for nutrient uptake data by the bulb and the whole plant for 2018 and 2020 only for treatments that received rates of compost (0, 10, 20, 30, and 60 t $ha^{-1}$) through the ExpDes package. The models that did not present significance for lack of fit were selected. Nutrient uptake data from the 2018 and 2020 crops for treatments that received rates of compost (0, 10, 20, 30, and 60 t $ha^{-1}$) were submitted to Pearson correlation analysis through the corrplot package to evaluate the interactions between nutrients as a function of the use of compost. Regression graphs were made in Sigmaplot software version 14.0.

## Results

### Onion yield

On October 24 and 25, 2019, a hailstorm occurred in the onion bulbification phase that drastically reduced the aerial part of onion plants and consequently reduced the onion yield (Table 1). In 2020, except for the treatment that received mineral fertilizer (MF), the yield was higher than that obtained in 2018. In Table 1, as previously reported (Higashikawa et al. 2022), in 2018 and 2020, the yield from 10 Mg $ha^{-1}$ of compost is the same as that obtained with mineral fertilizers. The 10 Mg $ha^{-1}$ rate of compost provided to the onion in kg $ha^{-1}$: 116 of N, 128 of $P_2O_5$, 64 of $K_2O$ and other nutrients such as Ca, Mg, Cu, Zn, Fe, and Mn, while the treatment with mineral fertilizer provided to the onion in kg $ha^{-1}$: 150 of N, 158 of $P_2O_5$, and 128 of $K_2O$.

### Effect of treatments on soil fertility

In general, soil fertility for the treatment that received mineral fertilizers (MF) was similar in the three years (Table 2). Regarding the treatments that received the rates of compost, there was an increase in CEC*p* and the contents of P, K, OM, Cu, and Zn by increasing compost amounts (Higashikawa et al.

2022). However, it is worth mentioning that P, Cu, and Zn can accumulate in the soil due to manure and organic residue application (Westerman and Bicudo 2005).

### *Effect of treatments on nutrient uptake by the bulb in 2018 and 2020*

Data from the effect of the treatment and the year in the uptake of nutrients by the bulb are presented in Table 3. As an individual factor, the treatment significantly influenced ($p < .05$) the bulb's uptake of N, P, K, Ca, Mg, S, Mn, Zn, Cu, and B. However, it did not significantly influence the Fe. The year as an individual factor significantly affected the uptake of all nutrients. There was generally less uptake of P, K, Ca, Mg, S, Zn, and B by the bulb in 2020 compared to 2018. On the other hand, there was a general increase in the uptake of N, Fe, Mn, and Cu by the bulb in 2020 compared to 2018. The interaction between treatment and the year was significant ($p < .05$) for N, K, Ca, Mg, Zn, Cu, and B. However, this interaction was not significant for P, S, Fe, and Mn. Regarding the reference values (Kurtz et al. 2016), the means of treatments for the N, K, and Zn uptake values by the bulb in our study were higher in the two years evaluated. In 2018 the sequence of nutrient uptake by the bulb considering the means of treatments in decreasing order was K>N>Ca>P>S>Mg>Zn>Fe>B>Mn>Cu, and in 2020 it was N>K>P>Ca>S>Mg>Fe>Zn>Mn>Cu>B. The reference values we used in Tables 3 and 4 refer to the cultivar Epagri 352 – Bola Precoce, which has the same production cycle as the SCS373 Valessul. However, to obtain these reference values, the cultivar Bola Precoce was cultivated in the no-tillage system on millet straw, only with mineral fertilization, with a population of 250,000 plants per hectare and lower productivity than the present study (37.3 Mg $ha^{-1}$). In addition, Bola Precoce has a genetic basis similar to Valessul, and the conditions for obtaining the data were similar to that of our study.

### *Effect of treatments on nutrient uptake by the whole plant (shoot + bulb) in 2018 and 2020*

Data from the effect of treatment and year on nutrient uptake by the whole plant are presented in Table 4. As an individual factor, the treatment significantly influenced ($p < .05$) the whole plant's uptake of N, P, K, Ca, Mg, S, Mn, Zn, Cu, and B. Iron was the only nutrient that was not influenced by the treatment in the uptake by the whole plant. As occurred for the bulb (Table 3), the year significantly influenced all nutrients uptake by the whole plant. In general, there was greater uptake of N, Mn, and Cu in 2020 compared to 2018, and in general, the reverse occurred for the uptake by the whole plant of the other nutrients. Significant interaction ($p < .05$) between the treatment and year factors for uptake N, K, Ca, Mg, Fe, Mn, Zn, Cu, and B. There was no significant interaction for the uptake of P and S by the whole plant. The means contents of K, Mg, and Zn of the treatments of our study were uptake by the whole plant in higher amounts than the reference values (Kurtz et al. 2016). In 2018 the sequence of nutrient uptake by the whole plant considering the averages of the treatments in decreasing order was K>N>Ca>P>S>Fe>Zn>Mg>Mn>B>Cu, and in 2020 it was N>K>Ca>P>S>Mg>Fe>Zn>Mn>Cu>B.

### *Principal component analysis (PCA) of nutrient uptake by the bulb and by the whole plant in 2018 and 2020*

The first two main components of the bulb PCA explain 78% of the data variability (Figure 2a) with the formation of two groups. One group is formed only by the treatment that did not receive a rate of compost (0 t $ha^{-1}$) that promoted the lowest uptake of nutrients by the bulb to the other treatments. The other treatments form the other group. In this group, except for the treatment of 10 t $ha^{-1}$ of compost, the other treatments (20, 30, 60 t $ha^{-1}$ of compost and MF) stood out mainly for the higher uptake of P, Zn, S, Mg, and K by the bulb, because they are in the same quadrant of the graph. Regarding the uptake of nutrients by the whole plant, all the first two main components of PCA explain 76.7% of the variability of the data. There are also two groups in this biplot (Figure 2b). Moreover, in the first group are rates of 0 and 10 t $ha^{-1}$ of compost, and in the other group are the other treatments. Treatments 0 and 10 t $ha^{-1}$ of compost promoted less nutrient uptake throughout

**Table 3.** Nutrient uptake by the bulb. The same capital letters in the column do not differentiate the years by the Scott-Knott mean test ($p < .05$). The same lowercase letters in the column do not differentiate treatments within each year by the Scott-Knott mean test ($p < .05$). ns = not significant; * = significant interaction ($p < .05$).

| Treatment | N | P | K | Ca | Mg | S | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | | | | | | | g ha$^{-1}$ | | | |
| | | | | | | 2018 | | | | | |
| 0 | 57.92 Bd | 19.05 b | 99.77 Ac | 27.97 Ac | 9.55 Ac | 13.05 d | 159.19 a | 40.59 b | 158.01 Ab | 15.64 Ba | 89.91 Ad |
| 10 | 69.76 Bc | 20.40 b | 114.24 Ab | 30.51 Ab | 11.10 Ab | 14.96 c | 188.65 a | 41.64 b | 171.99 Ab | 26.15 Ba | 105.54 Ac |
| 20 | 78.12 Bb | 23.07 a | 119.71 Aa | 30.06 Ab | 10.72 Ab | 18.23 b | 115.92 a | 47.36 b | 179.85 Ab | 23.23 Ba | 104.68 Ac |
| 30 | 89.57 Aa | 26.60 a | 129.10 Aa | 31.65 Ab | 11.74 Aa | 21.30 a | 226.66 a | 66.29 a | 205.06 Aa | 20.39 Ba | 115.64 Ab |
| 60 | 77.55 Bb | 24.43 a | 127.98 Aa | 30.50 Ab | 11.15 Ab | 19.30 b | 184.76 a | 63.02 a | 210.19 Aa | 28.15 Ba | 125.74 Aa |
| MF | 86.30 Aa | 24.54 a | 128.38 Aa | 35.62 Aa | 12.27 Aa | 19.55 b | 165.96 a | 68.98 a | 205.87 Aa | 25.53 Ba | 103.01 Ac |
| Mean | 76.54 | 23.02 | 119.87 | 31.06 | 11.09 | 17.74 | 173.53 | 54.65 | 188.50 | 23.19 | 107.42 |
| | | | | | | 2020 | | | | | |
| 0 | 74.71 Ab | 16.52 c | 69.58 Bb | 17.90 Ba | 9.17 Aa | 7.68 c | 172.95 a | 69.02 b | 106.70 Bd | 53.21 Ab | 33.01 Bb |
| 10 | 94.52 Aa | 20.12 b | 82.91 Ba | 17.21 Ba | 9.88 Ba | 9.65 c | 188.07 a | 80.80 b | 134.43 Bc | 60.01 Aa | 38.41 Bb |
| 20 | 97.00 Aa | 22.38 a | 88.87 Ba | 18.53 Ba | 10.06 Aa | 12.79 b | 251.43 a | 95.00 a | 183.60 Ab | 69.26 Aa | 44.63 Ba |
| 30 | 90.86 Aa | 22.56 a | 84.44 Ba | 18.18 Ba | 9.67 Ba | 12.31 b | 239.31 a | 87.76 b | 159.10 Bc | 65.04 Aa | 43.41 Ba |
| 60 | 99.11 Aa | 24.55 a | 92.35 Ba | 16.79 Ba | 8.83 Ba | 14.83 a | 233.32 a | 110.77 a | 216.08 Aa | 50.43 Ab | 49.86 Ba |
| MF | 96.84 Aa | 20.54 b | 79.17 Bb | 18.25 Ba | 8.87 Ba | 14.85 a | 214.17 a | 103.66 a | 147.24 Bc | 59.05 Aa | 34.42 Bb |
| Mean | 92.18 | 21.12 | 82.89 | 17.82 | 9.42 | 12.02 | 216.55 | 91.17 | 157.86 | 59.51 | 40.63 |
| RV | 58.30 | 23.90 | 45.70 | 19.70 | 7.00 | —– | 285.90 | 62.70 | 61.90 | 24.10 | 155.90 |
| Anova | | | | | | | | | | | |
| Treatment | * | * | * | * | * | * | ns | * | * | * | * |
| Year | * | * | * | * | * | * | * | * | * | * | * |
| Treatment*Year | * | ns | * | * | * | ns | ns | ns | * | * | * |

0, 10, 20, 30, and 60 are rates of compost in Mg ha$^{-1}$ and MF = mineral fertilizer. RV = reference values (Kurtz et al. 2016). Anova = analysis of variance; Treatment = treatment factor; Year = year factor; Treatment*Year = interaction between these two factors.

**Table 4.** Nutrient uptake by the whole plant (shoot + bulb). The same capital letters in the column do not differentiate the years by the Scott-Knott mean test ($p < .05$). The same lowercase letters in the column do not differentiate treatments within each year by the Scott-Knott mean test.

| Treatment | N | P | K | Ca | Mg | S | Fe | Mn | Zn | Cu | B |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | kg ha$^{-1}$ | | | | | | g ha$^{-1}$ | | | | |
| | | | | | | 2018 | | | | | |
| 0 | 84.21 Bb | 24.11 b | 154.82 Ac | 57.56 Ab | 18.79 Aa | 18.51 c | 1108.82 Aa | 170.08 Ab | 231.03 Ab | 17.58 Ba | 162.41 Ac |
| 10 | 91.20 Bb | 23.94 b | 156.20 Ac | 56.62 Ab | 19.23 Aa | 19.38 c | 813.61 Aa | 138.53 Bc | 233.17 Ab | 28.54 Ba | 159.15 Ac |
| 20 | 101.65 Ba | 28.10 a | 171.41 Ab | 59.42 Ab | 19.62 Aa | 24.11 b | 885.82 Aa | 210.66 Aa | 270.14 Aa | 28.91 Ba | 179.39 Ab |
| 30 | 113.03 Ba | 30.52 a | 172.33 Ab | 56.96 Ab | 19.04 Aa | 26.32 a | 1008.87 Aa | 212.67 Aa | 287.47 Aa | 24.44 Ba | 176.54 Ab |
| 60 | 106.71 Ba | 29.19 a | 183.77 Aa | 58.61 Ab | 18.79 Aa | 25.75 a | 923.06 Aa | 230.02 Aa | 307.12 Aa | 32.86 Ba | 208.13 Aa |
| MF | 112.75 Ba | 28.06 a | 175.44 Ab | 66.46 Aa | 20.76 Aa | 25.20 a | 960.76 Aa | 205.70 Ba | 290.39 Aa | 28.13 Ba | 164.83 Ac |
| Mean | 101.59 | 27.37 | 169.00 | 59.28 | 19.38 | 23.21 | 950.16 | 194.62 | 269.89 | 26.75 | 175.08 |
| | | | | | | 2020 | | | | | |
| 0 | 113.75 Ab | 20.70 c | 106.74 Bc | 37.08 Bb | 16.29 Bb | 12.34 d | 486.70 Ba | 171.37 Ad | 157.56 Bc | 70.40 Ab | 57.21 Bc |
| 10 | 141.12 Aa | 25.11 b | 133.88 Ba | 40.35 Bb | 18.67 Aa | 15.55 c | 660.77 Aa | 208.24 Ac | 195.90 Bb | 76.28 Aa | 69.33 Bb |
| 20 | 142.32 Aa | 27.14 a | 137.38 Ba | 46.30 Ba | 18.11 Aa | 18.50 b | 829.64 Aa | 225.45 Ab | 274.49 Aa | 86.07 Aa | 82.40 Ba |
| 30 | 137.90 Aa | 27.65 a | 139.14 Ba | 42.82 Ba | 17.35 Ba | 19.87 b | 630.52 Ba | 218.62 Ab | 226.12 Bb | 86.60 Aa | 83.16 Ba |
| 60 | 137.37 Aa | 28.57 a | 135.19 Ba | 39.69 Bb | 14.35 Bc | 21.60 a | 672.99 Ba | 241.04 Ab | 291.32 Aa | 59.80 Ab | 86.26 Ba |
| MF | 135.43 Aa | 24.22 b | 122.27 Bb | 41.95 Ba | 15.91 Bb | 22.25 a | 723.27 Aa | 264.48 Aa | 202.58 Bb | 68.52 Ab | 64.38 Bb |
| Mean | 134.65 | 25.53 | 129.10 | 41.37 | 16.79 | 18.36 | 667.32 | 221.54 | 224.71 | 74.62 | 73.80 |
| RV | 101.40 | 34.90 | 86.50 | 46.60 | 12.10 | —– | 761.20 | 149.60 | 84.10 | 33.70 | 220.60 |
| Anova | | | | | | | | | | | |
| Treatment | * | * | * | * | * | * | ns | * | * | * | * |
| Year | * | * | * | * | * | * | * | * | * | * | * |
| Treatment*Year | * | ns | * | * | * | ns | * | * | * | * | * |

0, 10, 20, 30, and 60 are rates of compost in Mg ha$^{-1}$ and MF = mineral fertilizer. ($p < .05$). RV = reference values (Kurtz et al. 2016). Anova = analysis of variance; Treatment = treatment factor; Year = year factor; Treatment*Year = interaction between these two factors. ns = not significant; * = significant interaction ($p < .05$).

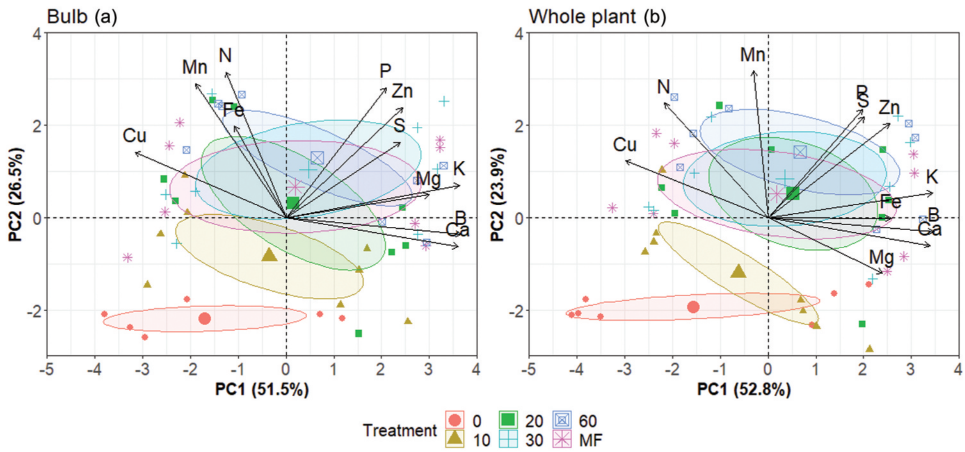


Figure 2. Principal component analysis (PCA) of the nutrients uptake by the bulb (A) and by the whole plant (B) according to the treatments in the 2018 and 2020 crops to the first two principal components (Pc1xpc2). Legend: MF = mineral fertilizer; 0, 10, 20, 30, and 60 are the rates of compost in Mg ha $^{-1}$.

the whole plant. The group formed by treatments 20, 30, and 60 t ha$^{-1}$ of compost and MF is present mainly in the same quadrant as P, S, Zn, and K, indicating that they promoted greater uptakes of these nutrients in the whole plant.

## Regression analysis for nutrients uptake by the bulb and by the whole plant in 2018 and 2020 as a function of applying compost rates

### Nitrogen

The maximum uptake of N by the bulb in 2018 was 88.00 kg ha$^{-1}$ with a rate of 38.12 Mg ha$^{-1}$ of compost (Figure 3a). In turn, in 2020 maximum uptake of N by the bulb was 97.39 kg ha$^{-1}$ with a rate of 16.57 Mg ha$^{-1}$. When considering the whole plant in 2018, the maximum uptake of N was 112.18 kg ha$^{-1}$ with a rate of 42.78 Mg ha$^{-1}$. In 2020 the maximum uptake of N by the whole plant was 144.34 kg ha$^{-1}$ with a rate of 17.57 Mg ha$^{-1}$.

### Phosphorus

The rate of 42.32 Mg ha$^{-1}$ of compost conferred the maximum uptake of 25.95 kg ha$^{-1}$ of P by the bulb in 2018 (Figure 3b). In 2020, 118.7 g ha$^{-1}$ of P was uptake for each megagram of compost added by the bulb. Regarding the uptake of P by the whole plant in 2018, the maximum P uptake was 33.05 kg ha$^{-1}$ with a rate of 42.89 Mg ha$^{-1}$. In turn, in 2020, the maximum P uptake was 29.18 kg ha$^{-1}$ with a rate of 45.83 Mg ha$^{-1}$.

### Potassium

In 2018 the rate of 44.95 Mg ha$^{-1}$ of compost conferred the maximum uptake of 131.55 kg ha$^{-1}$ of K per bulb (Figure 3c). In turn, in 2020, the response of the bulb became linear, and for each megagram of compost that was added, there was an increase of 304.40 g ha$^{-1}$ of K. It was not possible to adjust the regression curve for the uptake of K by the whole plant as a function of applied rates in 2018. However, in 2020 the whole plant's maximum uptake of 145.09 kg ha$^{-1}$ of K was checked by 38.43 Mg ha$^{-1}$ of compost.

### Calcium

In the case of Ca, it was only possible to adjust the curve for bulb uptake in 2018 (Figure 3d). In 2018 the bulb presented maximum uptake of 31.57 kg ha$^{-1}$ of Ca for the rate of 38.28 Mg ha$^{-1}$ of compost.

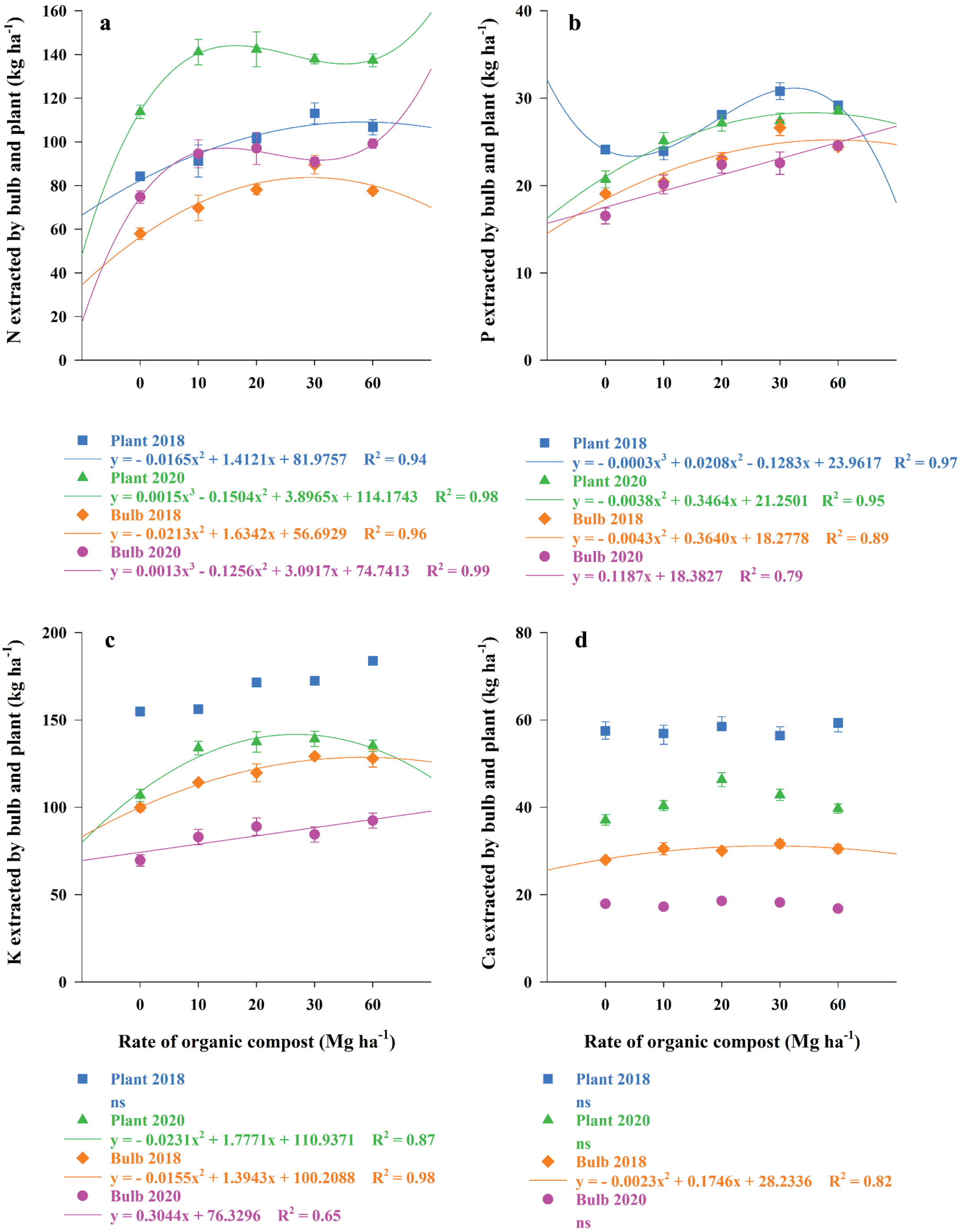


**Figure 3.** Uptake of N, P, K, and Ca by the bulb and by the whole plant in the onion crops in the no-tillage system in 2018 and 2020 as a function of applying rates of compost.

### Magnesium

For Mg, it was possible to adjust only the whole plant's uptake curve in 2020 (Figure 4a). The maximum uptake of 18.09 kg ha$^{-1}$ of Mg by the whole plant in 2020 was conferred by the rate of 21.81 Mg ha$^{-1}$ of compost.

### Sulfur

The maximum uptake of 23.06 kg ha$^{-1}$ of S by the bulb in 2018 was checked by the rate of 42.87 Mg ha$^{-1}$ (Figure 4b). In turn, in 2020, for each megagram of compost added, the bulb uptake 111.80 g ha$^{-1}$ of S. It was not possible to adjust the regression curve for the S uptake by the whole plant in 2018 as a function of the rates of compost applied. However, in 2020 the maximum uptake of 21.79 kg ha$^{-1}$ of S was conferred by the rate of 52.14 Mg ha$^{-1}$.

### Iron

It was not possible to adjust curves for the Fe uptake by the bulb in 2018 and 2020 according to compost rates (Figure 4c). However, there were adjustments to cubic equations for the uptake of Fe by the whole plant both in 2018 and 2020. In 2018 the maximum uptake of 1,221.72 g ha$^{-1}$ of Fe was checked by the rate of 46.00 Mg ha$^{-1}$, and in 2020, the uptake of 761.07 g ha$^{-1}$ of Fe was conferred by the rate of 16.68 Mg ha$^{-1}$.

### Manganese

The maximum uptake of 75.59 g ha$^{-1}$ of Mn by the bulb in 2018 was checked by the rate of 44.46 Mg ha$^{-1}$ (Figure 4d). In turn, in 2020, the bulb uptake 635.20 mg ha$^{-1}$ of Mn for each megagram of compost. It was not possible to adjust the regression curve for the Mn uptake by the whole plant in 2018 as a function of applying compost rates. However, in 2020 the maximum uptake of 222.76 g ha$^{-1}$ of Mn by the whole plant was conferred by the rate of 21.68 Mg ha$^{-1}$.

### Zinc

There was no adjustment of curves for the Zn uptake by the bulb and the whole plant in 2020 as a function of applying compost rates (Figure 5a). In 2018, 885.70 mg ha$^{-1}$ of Zn per bulb increased for each megagram of compost applied. Regarding the whole plant in 2018, there was an increase of 1.36 g ha$^{-1}$ of Zn for each megagram of compost applied.

### Copper

The maximum uptake of 25.63 g ha$^{-1}$ of Cu by the bulb in 2018 was conferred by a rate of 13.90 Mg ha$^{-1}$ of compost (Figure 5b). In 2020, the maximum Cu uptake of 67.25 g ha$^{-1}$ per bulb was checked by the rate of 28.55 Mg ha$^{-1}$. The maximum Cu uptake of 29.79 g ha$^{-1}$ by the whole plant in 2018 was checked by the rate of 15.59 Mg ha$^{-1}$. In 2020 the rate of 26.86 Mg ha$^{-1}$ conferred the whole plant's maximum uptake of 86.10 g ha$^{-1}$ of Cu.

### Boron

The uptake of B by the bulb in 2018 and 2020 was linear (Figure 5c). In 2018, the bulb uptake 550.10 mg ha$^{-1}$ of B for each megagram of compost added. In the 2020 crop, there was a lower uptake of B and for each megagram of compost added, the bulb uptake 258.00 mg ha$^{-1}$ of B. It was not possible to adjust the curve for the B uptake by the whole plant in 2018 as a function of applying compost rates; however, in 2020, the maximum uptake of 89.23 g ha$^{-1}$ of B by the whole plant was checked by the rate of 45.45 Mg ha$^{-1}$.

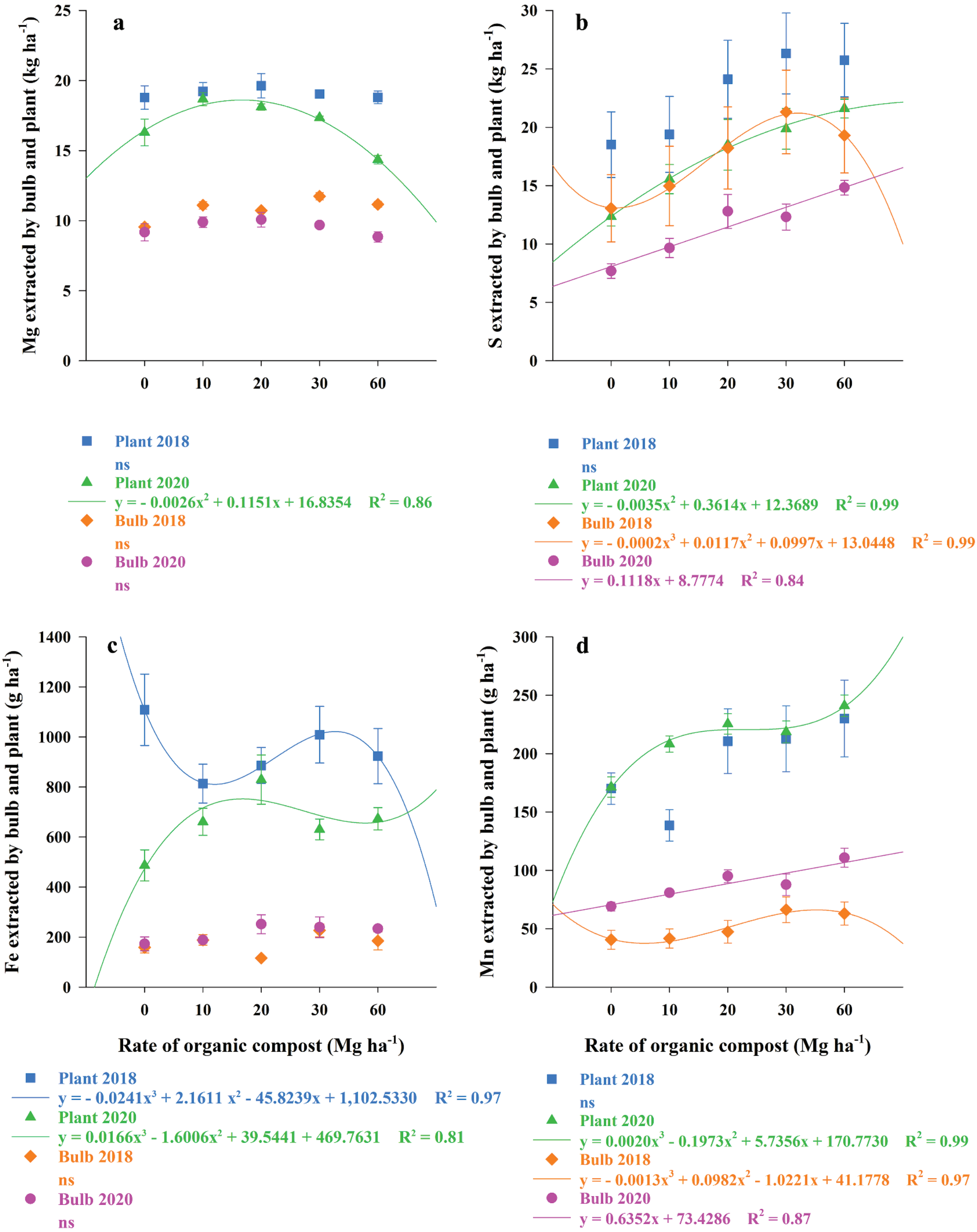


**Figure 4.** Uptake of Mg, S, Fe, and Mn by the bulb and by the whole plant in the onion crops in the no-tillage system in 2018 and 2020 as a function of applying rates of compost.

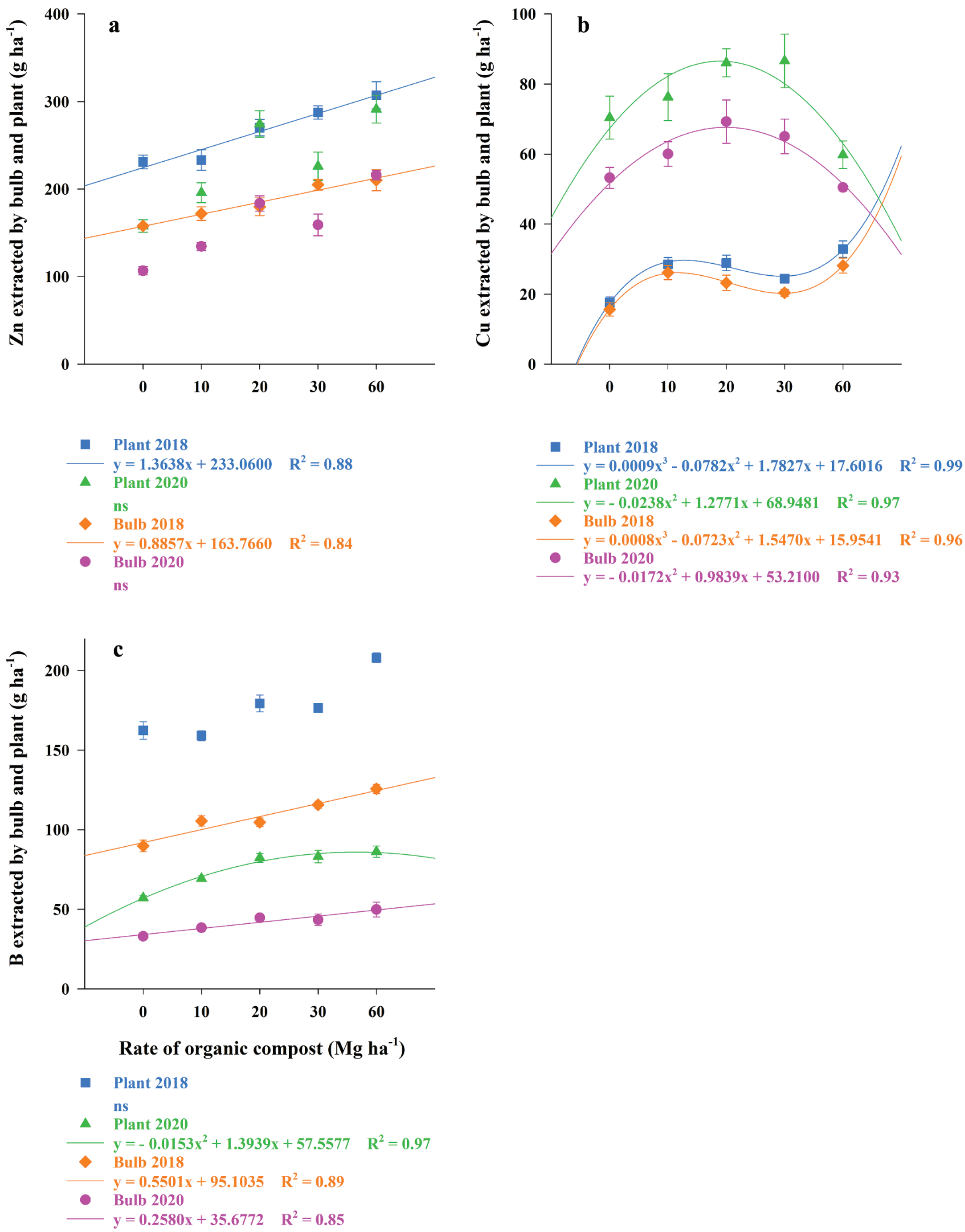


**Figure 5.** Uptake of Zn, Cu, and B by the bulb and by the whole plant in the onion crops in the no-tillage system in 2018 and 2020 as a function of applying rates of compost.

### *Pearson correlation of nutrients uptake by the bulb in 2018 and 2020 as a function of compost rates*

Phosphorus was the nutrient that presented the most positive and significant correlation with other nutrients (Figure 6). The positive correlations of P were with N, Mn, B, Mg, K, S, and Zn. Then the nutrients that presented the most positive correlation with other nutrients were Ca, B, Mg, K, S, and Zn. Calcium showed a positive correlation with B, Mg, K, S and Zn, boron with Mg, K, S, Zn and P, magnesium with K, S, Zn, P, Ca and B, potassium with Ca, B, Mg, S, Zn and P, sulfur with Ca, B, Mg, K, Zn and zinc with Ca, B, Mg, K, S and P. The nitrogen showed a positive correlation with Fe, Mn, Cu, P and manganese with N, Fe, Cu and P. Nutrients that presented a lower number of positive correlations were Fe that correlated only with N, Mn, and Cu and Cu that correlated only with N, Fe, and Mn. The highest positive correlation values were between Ca and B, Ca and K, B and K, and Zn and P. Regarding the negative and significant correlation, Cu was the nutrient that presented the most negative correlations with other nutrients. The negative correlations of Cu were with Ca, B, Mg, K, and S. Calcium and B showed a negative correlation with three nutrients, and Ca correlated negatively with N, Mn, and Cu and B with N, Mn, and Cu. Magnesium correlated negatively with Cu. The Mn correlated negatively only with Ca and B. The most prominent negative correlations were between Cu and Ca and between B and Cu.

### *Pearson correlation of the nutrients uptake by the whole plant in 2018 and 2020 as a function of compost rates*

The uptake of nutrients by the whole plant (Figure 7) showed more positive and negative correlations than nutrient uptake by the bulb (Figure 6). Calcium, B, K, S, and Zn were the nutrients with the highest positive and significant correlations. Calcium positively correlated with Mg, P, Zn, S, K, Fe and B, boron with Ca, Mg, P, Zn, S, K and Fe, potassium with P, Zn, S, Fe, B, Ca and Mg, sulfur with Mn, P, Zn, K, Fe, B and Ca and zinc with Mn, P, S, K, Fe, B and Ca. Phosphorus positively correlated with Mn, Zn, S, K, B, Ca, and Fe with Zn, S, K, B, Ca, and Mg. Manganese positively correlated with P, Zn, S, and N. Copper had a positive correlation only with N. The positive and significant correlations that stood out were between P and Zn, K with B and Ca, B and Ca, and Cu and N. As occurred for the bulb (Figure 6) the Cu was the nutrient that presented the most negative and significant correlation for nutrient uptake by the whole plant (Figure 7). The Cu showed a negative correlation for S, K, Fe, B, Ca, and Mg. After Cu, N was the nutrient that presented the most negative correlation and was with the following nutrients: K, Fe, B, Ca, and Mg. Magnesium presented a negative correlation with Mn, Cu, and N. Manganese presented a negative correlation only with Mg. The negative correlations that stood out were between Cu with K, B, and Ca and N with B and Ca.

## Discussion

### *Nutrient uptake*

According to Figure 2, the compost promotes onion nutrition similar to that provided by mineral fertilizers. Therefore, it is possible to replace mineral fertilizers with compost in onion cultivation under a no-tillage system. In addition, organic fertilizer is recommended due to its beneficial effects on the soil's physical, chemical, and biological properties (Kazimierczak et al. 2021). Furthermore, due to similar yields, organic fertilizers can replace mineral fertilizers in onion culture (Gonçalves and Silva 2003; Higashikawa et al. 2022). However, verifying if the compost complies with the current legislation and if the transport cost is viable is necessary (Kurtz, Menezes Júnior, and Higashikawa 2018). In Figure 2, there was the formation of two groups with opposite correlations in the bulb; the first group is N, Fe, Mn, and Cu, and the second group is the other nutrients. When considering the whole plant, the first group is N, Mn, and Cu, and the second group is the other nutrients. A possible reason is the different nutrient uptake by the bulb and the shoot (Tables 3 and 4) and the correlation between nutrients (Figures 6 and 7). By analyzing Tables 3 and 4, it is possible to verify that Fe and Mn accumulated more in the shoot of the onion, which is in agreement with the study by Kurtz et al. (2016) and Kurtz, Fayad, and Vieira Neto (2020).

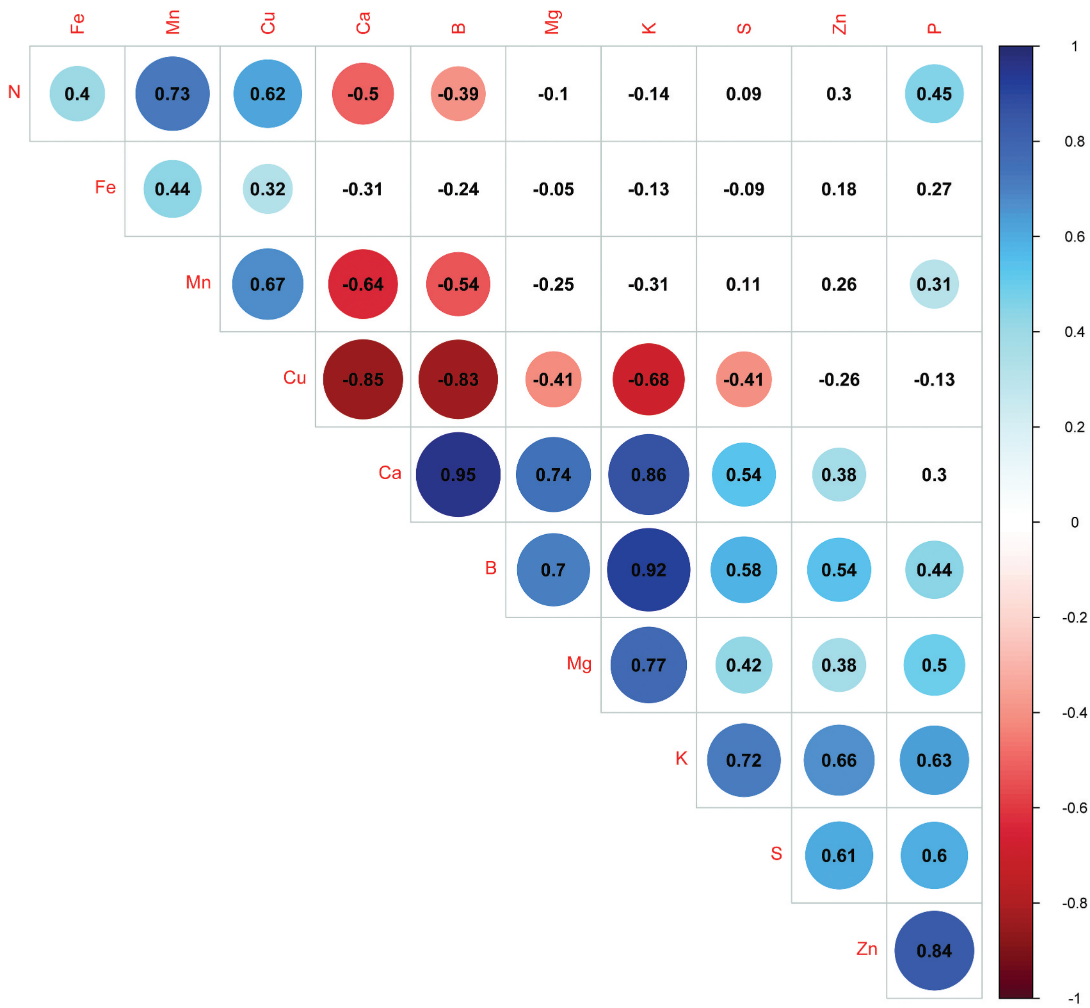


**Figure 6.** Pearson correlation for the nutrients uptake by the bulb in 2018 and 2020 harvests as a function of applying rates of compost. Non-significant correlation coefficients are blank. Negative and significant correlation coefficients are in red circles. Positive and significant correlation coefficients are in blue circles. The larger the circle and the more intense the shade of red or blue, the greater the correlation coefficient value.

### *Nitrogen*

In a review on nitrogen nutrition and fertilization of onion, Geisseler, Ortiz, and Diaz (2022) reported that the average N content in the bulb is 1.7 kg $Mg^{-1}$ of fresh matter. According to Tables 1 and 3, the mean N content in the bulb in 2018 was 1.61 kg $Mg^{-1}$ of fresh matter. However, in 2020 the average rose to 1.87. This increase in the average N content in the bulb and the whole plant in 2020 compared to 2018 was probably due to the accumulation of total nitrogen on the soil surface due to cover crops in the no-tillage system (Comin et al. 2018). However, the N derived from the decomposition of cover plant residues contributes little to the development of onion (Koucher et al. 2017). However, compost rates in each crop contributed to the increase in soil organic matter content (Table 2), consequently increasing nitrogen availability for onions in 2020. According to the review work of Geisseler, Ortiz, and Diaz (2022), on average, 65% of the N uptake by the onion is in the bulb. In our study, the mean N content in the bulb was 75.06% in 2018 and 68.29% in 2020. Regarding the N uptake values by the bulb (Table 3), they are within the range found in the literature that is in kg $ha^{-1}$ from 28.65 (May et al.

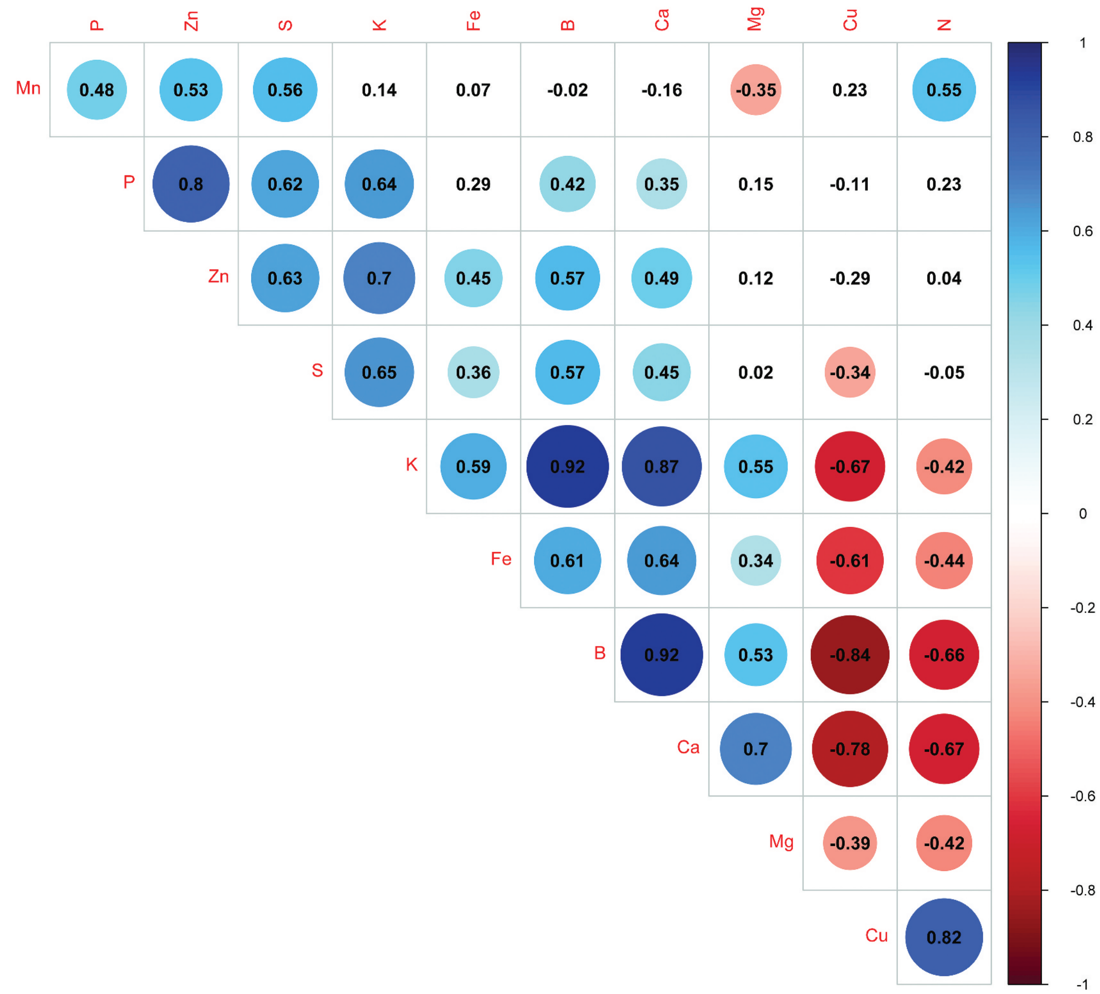


**Figure 7.** Pearson's correlation for the nutrients uptake by the whole plant in 2018 and 2020 harvests as a function of applying rates of compost. Non-significant correlation coefficients are blank. Negative and significant correlation coefficients are in red circles. Positive and significant correlation coefficients are in blue circles. The larger the circle and the more intense the shade of red or blue, the greater the correlation coefficient value.

2008) to 115.90 (Lee et al. 2014). The *N* values uptake by the whole plant (Table 4) are within the range found in the literature that is in kg ha$^{-1}$ from 61.22 (Pôrto et al. 2006) to 157.20 (Moraes et al. 2016). As most of the N is required by the onion is at the beginning of the bulbification (Khokhar 2019), which occurs around 60 DAT, the application of the rates of compost in the transplant provided uptake of N equivalent to the treatment with mineral fertilizer mainly in 2020 (Tables 3 and 4). N mineralization at the beginning of the onion cycle was probably slow, but this did not affect the onion yield (Table 1) and the onion nutrition (Figure 2), as the onion nutrient requirement is slow until 60 days after transplanting seedlings (Kurtz et al. 2016).

### *Potassium*

Potassium was the most uptake nutrient in 2018 by both the bulb (Table 3) and the whole plant (Table 4), which is related to other studies (Backes et al. 2018;Moraes et al. 2016; Lee and Lee 2014; Vidigal, Moreira, and Pereira 2010). The nutrient being more uptake to be N or K depends on the cultivar, the soil, the climate, and the cultivation system (Kurtz et al. 2016). A factor that may have contributed to the higher uptake of K in 2018 (Tables 3 and 4) is because K is not structurally connected with any compost (Ernani et al. 2007), besides not being influenced by microorganisms (Brady and Weil 2013) to be available in soil solution. The K uptake values by the bulb (Table 3) are within the range found in the literature, ranging in kg ha$^{-1}$ from 32.80 to 180.60 (Aguiar Neto et al. 2014). The K uptake values by the whole plant (Table 4) are within the range found in the literature (kg ha$^{-1}$), which is from 68.28 (May et al. 2008) to 256.20 (Moraes et al. 2016). Potassium promotes root and leaf growth, increases photosynthetic activity to initiate bulb formation, improves water absorption, and protects culture against diseases and adverse weather conditions (Khokhar 2019).

### Calcium

Calcium was the third nutrient most uptake by the whole plant (Table 4). However, in the study by (Moraes et al. 2018), Ca was the second most uptake nutrient after K, and with Ca uptake by the whole plant of 120.80 kg ha$^{-1}$ and by the bulb, the uptake was 46.7 kg ha$^{-1}$, which are higher values than those obtained in our study (Tables 3 and 4). Aguiar Neto et al. (2014) verified that Ca was the nutrient most uptake by the bulb of the cultivars Texas Grano 502 (187.60 kg ha$^{-1}$) and IAP11 (68.10 kg ha$^{-1}$) when they were grown in Acrisol (Ultisol). On the other hand, when these cultivars were grown in Cambisol (Inceptisol), Ca was the second nutrient most uptake by the bulb by Texas Grano 502 (73.10 kg ha$^{-1}$) and the third most uptake by the bulb for IPA11 (27.40 kg ha$^{-1}$). The Ca uptake values by the bulb (Table 3) are within the range found in the literature ranging in kg ha$^{-1}$ from 12.50 (Lee et al. 2014) to 187.60 (Aguiar Neto et al. 2014). The Ca uptake values by onion (Table 4) are also within the range found in the literature, ranging in kg ha$^{-1}$ from 21.04 (Falodun and Egharevba 2018) to 120.80 (Moraes et al. 2018).

### Phosphorus

Phosphorus was the fourth nutrient most uptake by the whole plant (Table 4). The P uptake values by the bulb (Table 3) for the treatment that received 60 t ha$^{-1}$ of compost are above the range found in the literature ranging in kg ha$^{-1}$ from 4.40 (Aguiar Neto et al. 2014) to 23.90 (Kurtz et al. 2016). Possibly, the high levels of P in the soil as a function of the application of compost (Table 2) contributed to higher availability of P and consequently to greater uptake of P. The increase in available P is probably not only due to the P content in the compost, but also to the reduction of P adsorption sites in the soil provided by organic acids (Novais, Smyth, and Nunes 2007; Penha et al. 2015). In addition, the P is a moving element in the plant (Malavolta 2006) and there was a redistribution of the P from the leaves to the bulb. These P uptake values by the whole plant (Table 4) are within the range found in the literature ranging in kg ha$^{-1}$ from 7.32 (Falodun and Egharevba 2018) to 34.90 (Kurtz et al. 2016).

### Sulfur

In our study, S was the fifth nutrient most uptake by the whole plant (Table 4). In other studies, S was the fourth most uptake nutrient by onion (Backes et al. 2018; Moraes et al. 2018; Pôrto et al. 2006, 2007; May et al. 2008; Vidigal, Moreira, and Pereira 2010). The S uptake values by the bulb (Table 3) for treatments 0 and 10 t ha$^{-1}$ of compost are below the values range found in the literature in kg ha$^{-1}$ from 11.51 (May et al. 2008) to 28.29 (Backes et al. 2018). The S uptake values by the whole plant in 2020 (Table 4) are below the range of values found in the literature in kg ha$^{-1}$ from 24.38 (May et al. 2008) to 53.20 (Moraes et al. 2016). The factors that may have contributed to the lower uptake of S by onion are the preference for phosphate adsorption by the soil regarding sulfate, the formation of ionic pair with potassium, and the movement of sulfur to deeper soil layers (Furtini Neto et al. 2001).

### Magnesium

Magnesium was the macronutrient least uptake by the whole plant (Table 4), which agrees with other studies (Moraes et al. 2018; May et al. 2008; Vidigal, Moreira, and Pereira 2010). However, in other studies (Pôrto et al. 2006, 2007), P was the macronutrient least uptake for the cultivar Superex in May et al. (2008). This Mg uptake values by the bulb (Table 3) are within the range found in the literature that ranged in kg ha$^{-1}$ from 3.65 (Menezes Júnior, de Gonçalves, and Kurtz 2013) to 39.70 (Aguiar Neto et al. 2014). These Mg uptake values by the whole plant (Table 4) are within the range found in the literature, ranging in kg ha$^{-1}$ from 8.90 (Falodun and Egharevba 2018) to 26.10 (Backes et al. 2018).

### Iron

Iron was the micronutrient most uptake by the whole plant (Table 4), which agrees with other studies (Backes et al. 2018; Moraes et al. 2016, 2018; Kurtz et al. 2016; Kurtz, Fayad, and Vieira Neto 2020). Iron uptake values by the bulb, except for the treatmentof 30 t ha$^{-1}$ of compost in 2018 and except for the treatments 20, 30, and 60 t ha$^{-1}$ of compost and MF in 2020 (Table 3), are below the range found in the literature that varied in g ha$^{-1}$ of 208.60 (Kurtz, Fayad, and Vieira Neto 2020) to 2,029.32 (Menezes Júnior, de Gonçalves, and Kurtz 2013). In 2020 there was less Fe uptake compared to 2018. Thus, except for treatments with mineral fertilization (MF) and the rate of 20 t ha$^{-1}$ of compost, the other treatments presented Fe uptake in 2020 below the range found in the literature that varied in g ha$^{-1}$ from 720.00 (Moraes et al. 2018) to 2,760.00 (Backes et al. 2018). The negative correlation between Cu and Fe (Figure 7) may have contributed to the lower uptake of Fe since there was greater Cu uptake in 2020 compared to 2018 and the opposite occurred for Fe.

### Zinc

Zinc was the second micronutrient most uptake by the whole plant (Table 4). The Zn uptake values by the bulb (Table 3) are within the range found in the literature that varied in g ha$^{-1}$ from 18.41 (Menezes Júnior, de Gonçalves, and Kurtz 2013) to 1,018.33 (Bertino et al. 2022). Moreover, the Zn uptake values by the whole plant (Table 4) are within the range found in the literature, ranging in g ha$^{-1}$ from 84.10 (Kurtz et al. 2016) to 1,053.33 (Bertino et al. 2022). The onion is in the group of crops with high sensitivity to Zn deficiency (Alloway 2008) and presents a response to the addition of Zn in the soil (Kurtz and Ernani 2010). However, due to the root system being poorly developed (Geisseler, Ortiz, and Diaz 2022), a smaller volume of soil is explored, and a higher concentration of Zn in the soil is necessary to meet the requirements of the onion (Kurtz, Menezes Júnior, and Higashikawa 2018).

### Manganese

Manganese was the third micronutrient most uptake by the whole plant (Table 4). The Mn uptake values by the bulb (Table 3) by treatments 0, 10, and 20 t ha$^{-1}$ of compost are below, and the others are within the range found in the literature, ranging in g ha$^{-1}$ from 52.11 (Backes et al. 2018) to 304.51 (Vidigal, Moreira, and Pereira 2010). The Mn uptake values by the whole plant (Table 4) are within the range found in the literature, ranging from g ha$^{-1}$ from 84.00 (Backes et al. 2018) to 742.55 (Vidigal, Moreira, and Pereira 2010). The largest uptake of Mn in 2020 for both the bulb and the whole plant may be due to the positive correlation (Figures 6 and 7) with N since there was also greater N uptake in 2020.

### Copper

Copper was the least uptake micronutrient in 2018, but in 2020, it was B (Table 4). This alternation between the two micronutrients is probably due to the high negative correlation between these nutrients (Figures 6 and 7). Only the uptake of Cu by the treatment that did not receive compost in 2018 is below the range. The other Cu uptake values by the bulb (Table 3) are within the range found in the literature that varied in g ha$^{-1}$ from 16.27 (Menezes Júnior, de Gonçalves, and Kurtz 2013) to 271.67 (Bertino et al. 2022). The Cu uptake values by the whole plant (Table 4) are within the range found in the literature ranging from g ha$^{-1}$ from 33.70 (Kurtz et al. 2016) to 475.00 (Bertino et al. 2022). The increase in Cu uptake by the bulb (Table 3) and by the whole plant (Table 4) by the treatment that did not receive a rate of compost in 2020 may have been due to the recycling of nutrients promoted by the cover plants that were used in the experiment (CFSEMG 1999). In addition, there was a positive correlation of Cu with N (Figures 6 and 7). Both N and Cu had higher uptake in 2020.

### *Boron*

Boron was the micronutrient least uptake by the whole plant in 2020 (Table 4). The B uptake values by the bulb (Table 3) are within the range found in the literature in 2018 but below the range in 2020 that varied in g ha$^{-1}$ from 62.98 (Menezes Júnior, de Gonçalves, and Kurtz 2013) to 951.67 (Bertino et al. 2022). However, except for the treatment that received 60 t ha$^{-1}$ of compost in 2018, the other values (Table 4) are below the range found in the literature, ranging in g ha$^{-1}$ from 193.30 (Kurtz, Fayad, and Vieira Neto 2020) to 1,350.00 (Bertino et al. 2022). Probably, with the application of compost, there was an increase in Cu content in the soil (Table 2), and allied to that, there was a high negative interaction between B and Cu (Figures 6 and 7), which consequently may have contributed to the lower uptake of B in 2020 (Tables 3 and 4).

### *Correlation between nutrients*

Several external and internal factors may have contributed to the correlations between nutrients (Figures 6 and 7) and even to the behavior of nutrient uptake according to compost rates (Figures 3, 4, and 5). In addition, another factor is that onions have higher nutrient uptake by the bulb or by the shoot, depending on the nutrient, and each nutrient is required in different quantities (Kurtz et al. 2016; Kurtz, Fayad, and Vieira Neto 2020; Vidigal, Moreira, and Pereira 2010). According to Tables 3 and 4, Fe and Mn were more uptake by the shoot of the onion. Some of the external factors that can influence nutrient uptake are (Faquin 2005): nutrient availability, the presence and concentration of nutrients in the soil solution, the difference in speed that nutrients are uptake, and the interactions of inhibition and synergism between nutrients. The internal factors that can influence the uptake of nutrients are (Faquin 2005; Malavolta 2006): plant genetics, plant nutritional status, and root morphology. The negative correlation between N and K by the whole plant (Figure 7) may have been due to the competitive inhibition of $NH_4^+$ regarding $K^+$ (White 2012), which may have resulted in the lower uptake of K by the whole plant in 2020 (Table 4). Possibly, noncompetitive inhibition between N and B and between N and Mg (Malavolta 2006) resulted in negative correlations between these nutrients (Figure 7). The increase in P supply can reduce the uptake of Zn by the roots and reduce the translocation of Zn from root to shoot (Bucher et al. 2018). However, in our study, there was no negative correlation between P and Zn (Figures 6 and 7), and on the contrary, there was a positive correlation between these nutrients. Both P and Zn had lower uptake in 2020 compared to 2018 (Tables 3 and 4), probably due to other factors, since P and Zn did not present negative correlations with other nutrients (Figures 6 and 7). The increase in P and Zn contents in the soil as a function of increased rates of compost (Table 2) may have contributed to the positive correlations between these nutrients in our study. Provably, there was a synergistic effect between B with Ca, Mg, K, S, Zn, and P (Figure 6) and between B with P, Zn, S, K, Fe, Ca, and Mg (Figure 7) due to extracellular $Ca^{2+}$ stimulus in uptake these nutrients (White 2012).

In future studies, it will be necessary to evaluate the residual effect of the application of the compost to observe the yield and nutrition of onion in a no-tillage system, but only having as a source of nutrients what was accumulated in the soil. Thus, it will be possible to verify the time of a new application of compost rates in the same area according to soil availability and onion requirement.

## Conclusions

The compost can replace mineral fertilizers for onion production in a no-tillage system as long as it meets the legislation and the transport cost is viable. The agricultural use of organic waste as compost brings agronomic benefits and simultaneously reduces environmental liabilities. From the rate of 10 Mg ha$^{-1}$ of compost, the uptake of nutrients by the bulb is similar to that observed with mineral fertilizers. Therefore, the addition of compost improves soil fertility and meets the nutritional need of onion. Every year, compost rates in the same area require monitoring of soil fertility due to nutrient accumulation, mainly of K, P, Cu, and Zn.

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## Disclosure statement

No potential conflict of interest was reported by the author(s).

## ORCID

Fábio Satoshi Higashikawa http://orcid.org/0000-0002-5601-7931
Rafael Ricardo Cantú http://orcid.org/0000-0003-2884-9340
Keiji Jindo http://orcid.org/0000-0001-6963-355X
Claudinei Kurtz http://orcid.org/0000-0002-1688-6139
Paulo Antônio de Souza Gonçalves http://orcid.org/0000-0002-4480-9499
João Vieira Neto http://orcid.org/0000-0002-2959-0038

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