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Macro and micronutrients accumulation in radish (*Raphanus sativus* L.) subjected to potassium (K) fertilization

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Abstract

The current study aims to evaluate the effects of potassium fertilization on yield, root quality, macro and micronutrients accumulation in radish production. The experiment was conducted using a randomized block design with five treatments consisted of potassium (K_2O) topdressing (0, 22.5, 45, 67.5 and 90 kg ha^{-1}) applied in the form of potassium chloride and five repetitions. Plants vegetative characteristics, yield, macro and micronutrient accumulation were evaluated in both roots and shoots. Results indicated that K_2O increased plant height (21.5 cm) at 90 kg ha^{-1}; in addition to root fresh mass (40.4 g), total fresh mass (115.2 g), yield (33.7 t ha^{-1}), Mg concentration in roots (2.9mg plant^{-1}) and B in leaves (3.6 mg plant^{-1}), being the best dose for this crop. The decreasing orders of macro and micronutrient accumulation in the shoots were N>P>K>Ca>S>Mg and Fe>Zn>Mn>Cu>B, respectively. The decreasing orders of macro and micronutrient accumulation in the roots were: K>P>N>Ca>S>Mg and Fe>Zn>Mn>Cu>B, respectively.

Keywords: *Raphanus sativus* L., Brassicaceae, doses of potassium, nutrition, productivity.
Abbreviations: CTC_ cation exchange capacity; C/N_ carbon/nitrogen; H + Al _ total acidity to pH 7; O. M _ organic matter; SB_ sum of bases; V_ base saturation.

Introduction

Radish (*Raphanus sativus* L.) is a brassicacae from the small Mediterranean region; such plants do not exceed 30cm in height and have well cut leaves (Matos et al., 2014). Radish is characterized by its white skin, yet the flesh has a strong pink colour and a pungent flavour; has nutraceutical and medicinal properties, since it is high in calcium, iron, vitamins (A, B1, B2 and C) and sulphur compounds, besides its anticarcinogenic, diuretic, antiscorbutic and stimulate digestive gland enzyme activities; the latter improves liver function to increase digestibility (Oliveira et al. al., 2014).

In Brazil, radish has small importance in terms of planted area, but is cultivated on a larger scale by small farms located in metropolitan areas of large centres (Camargo et al., 2007). The vegetable cycle is short (i.e. 35 days), which provides an interesting option for small-scale farmers to intercrop with other crops that presents longer cycles, such as pepper, tomato, cabbage and broccoli (Matos et al., 2014).

In general, vegetables present great nutritional requirement for their development and production, being potassium and nitrogen the most extracted macronutrients by them. Potassium (K) influences yield and the quality of the final product, which impacts on market value (Araújo et al., 2012). K has great importance in activating several enzymatic systems involved in plants metabolism; acting in the synthesis of proteins and adenosine triphosphate (ATP); in the processes of respiration, photosynthesis and transpiration; meristematic growth in the extension of plant cells; preservation of tissue turgidity; opening and closing of stomata; formation and translocation of carbohydrates. K increases frost resistance, as well as drought, salinity, disease, storage and maintenance of the quality of final product (Malavolta, 2006; Taiz and Zeiger, 2013).

K deficiency causes chemical changes in the vegetable, such as low-carbohydrate accumulation and water use efficiency. However, the excess of K can salinize soils; reduce calcium and magnesium absorption that leads to a decrease in production and the quality of final product (Fernandes, 2006). Potassium chloride (KCl) is the most used fertilizer, because it has a high concentration of potassium (60% K_2O) and offers the best cost-benefit ratio among main fertilizers (Novais et al., 2007). A challenge for vegetable growers has been to tailor management to maximize production, reduce costs, and mainly improve product shelf life. Therefore, it is necessary that crop management practices, such as well-planned fertilization promote an increase in yield and quality without leaving any wastage.

Therefore, potassium fertilization management must consider dosages, application methods, seasons and sources to be used; in addition to crop demand; fertilizer price; saline effect on plants, especially by leaching in tropical soils, because of the availability of non-exchangeable potassium (Niebes et al., 1993). There is a paucity of literature on specific potassium demand in radish crop, as well as crop productive success; therefore, the current study aims to evaluate the macro and micronutrients accumulation in radish production subjected to potassium topdressing fertilization.

Results

Production components

At different doses of K_2O topdressing, the production components of radish showed a significant effect ($p <0.05$) for plant height (cm), root fresh mass (g), total fresh mass (g) and yield (t ha^{-1}). The absence of significant effects ($p> 0.05$) of potassium fertilization on the other traits: transverse diameter (36.7 mm), root length (38.4 mm), shoot fresh mass (65.3 g), root dry mass (3.8 g), total dry mass (7.1 g), and especially commercial root percentage (96.3%) may be related to Rafina hybrid traits, which in turn presents good root uniformity and a high percentage of commercialization.

The height of radish was adjusted by a quadratic function of K doses; results indicated an increase in height of 29.75% (21.5cm) at 90 kg of K_2O ha^{-1}. Furthermore, the recommendation of K fertilization for radish (Trani et al., 1997), i.e. 45 kg of K_2O ha^{-1}, resulted in the lowest plant height (16.58 cm) (Figure 1A).

Figure 1B shows a linear increase in root fresh mass as a function of the K_2O topdressing. The values ranged from 31.10 g $plant^{-1}$ (0 kg of K_2O ha^{-1}) to 44 g $plant^{-1}$ (90 kg of K_2O ha^{-1}), with an average increase of 1.06 g in fresh mass for each 10 kg of K_2O ha^{-1}.

Shoot fresh mass was not affected by K_2O with an average of 65.3 g. Results increased linearly in total fresh mass of the plants (shoot and root) as doses enhanced, with averages between 50.22g (0 kg of K_2O ha^{-1}) and 68.77 g (90 kg of K_2O ha^{-1}) (Figure 1C). Results indicated an increase of 2.02 g in total fresh mass for each 10 kg of K_2O ha^{-1}.

Figure 1D shows that yield increased linearly with increasing K dose, therefore, every 10 kg of K_2O ha^{-1} increased of 1.05 t ha^{-1}. The highest dose (90 kg of K_2O ha^{-1}) increased the yield by 19.33% compared to the recommended dose for radish (i.e. 45 kg ha^{-1}) and hence a new fertilizer recommendation approach to improve radish yield.

Macronutrient accumulation in roots

Regarding to the macronutrient accumulation in roots and shoots submitted to different doses of K_2O, a significant effect ($p <0.05$) was only observed for magnesium in roots. The effect of potassium fertilization on nutrients in shoots presented nitrogen (56.5g $plant^{-1}$), phosphorus (40.5g $plant^{-1}$), potassium (46.5 g $plant^{-1}$), calcium (36.1 g $plant^{-1}$), magnesium (4.8 g $plant^{-1}$), and sulphur (6.3 g $plant^{-1}$). The decreasing order of greatest accumulation by the roots was K> P> N> Ca> S> Mg, with averages of 85.1> 50.5> 34.9> 7.1> 3.7> 2.6 g $plant^{-1}$, respectively. There was a significant effect on the accumulation of magnesium in the root, which increased linearly with increasing K doses (Figure 2A). In roots, magnesium accumulation was 10.9 % higher at the highest dose (90 kg ha^{-1}) than the recommended dose (45 kg ha^{-1}) for radish.

For micronutrients accumulation in shoots and roots of Rafina radish, a significant difference ($p <0.05$) was only observed for boron in the shoot and copper in the root, respectively. The order of decreasing micronutrient accumulation in the shoots of radish plants was Fe> Zn> Mn> Cu> B with averages of 81.8> 30.2> 17.7> 6.0> 2.95 mg $plant^{-1}$, respectively. For the roots, the decreasing order was: Fe> Zn> Mn> Cu> B with averages of 43.8> 43.0> 42.7> 7.2> 3.45 mg $plant^{-1}$, respectively.

Although they were not significantly influenced ($p> 0.05$) by K_2O topdressing, the average levels of iron in the shoots (81.8 mg $plant^{-1}$) and roots (43.8 mg $plant^{-1}$) were higher than the other micronutrients. These results can be explained by the high concentration of this nutrient in the soil and organic compound used (7525 mg kg^{-1}), which may have compromised the treatment effect on the response of this micronutrient in the different tissues of Rafina radish.

In shoots, boron accumulation was adjusted by a quadratic function of K_2O doses; therefore, the lowest values were obtained at recommended doses for radish (40 kg ha^{-1}) and the highest values were observed at 90 kg of K_2O ha^{-1} (Figure 2B).

Regarding to the copper accumulation in the roots, a linear effect was observed as a result of the increase of K_2O topdressing (Figure 2C), the highest accumulation of boron (2.4 mg $plant^{-1}$) was obtained at the dose of 90 kg ha^{-1}.

Discussion

Mineral nutrition has a fundamental importance in increasing yield and the quality of final products; being potassium the most extracted nutrient by them, since K plays a fundamental role in developing and forming such attributes. K directly influences the meristematic growth and extension of plant cells, as they stimulate cell stretching process; consequently, increasing production parameters at proper levels in plant tissues (Yamada and Roberts 2005).

The current study showed that the total fresh mass gain per radish plant can be explained by the importance of K in the activation processes of several enzymatic systems that participate within plant metabolism, such as photosynthesis, respiration, meristematic growth, cellular extension, water use efficiency, formation and translocation of carbohydrates; then, playing decisive role in plants normal growth rate (Taiz and Zeiger 2013; Yamada and Roberts 2005; Malavolta, 2006).

Before experiment, available K in soil was considered medium content, that is, 2.0 $mmol_c$ dm^{-3}, according to Raij et al. (1997); besides organic compound and NPK helped releasing K and doses above recommended by Trani et al. (1997). Thus, they all provided a significant response to this trait, showing this nutrient importance in radish production and yield.

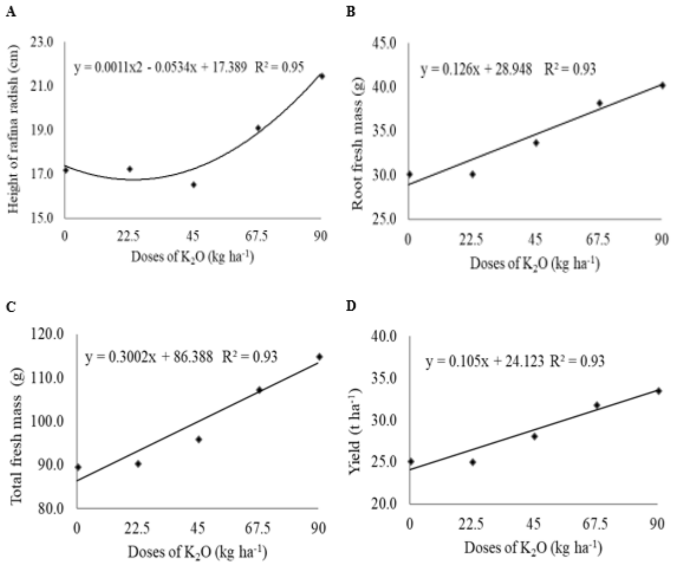

Fig 1. Height (A), root fresh mass (B), total fresh mass (C) and yield (D) of Rafina radish submitted to doses of K_2O topdressing.

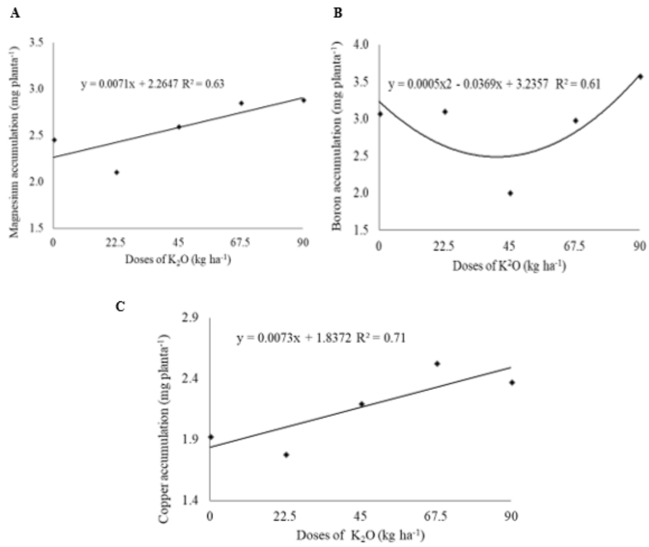

Fig 2. Average contents of magnesium (A), boron (B) and copper (C) accumulation (mg plant^{-1}) in the roots of Rafina radish submitted to doses of K_2O topdressing.

Moreover, there were other factors observed in this study, such as a healthy plants population, crop favourable weather (i.e. mild climate), sprinkle irrigation at adequate levels and the absence of pathogen and pests.

Trani et al. (1997) recommended an average of 45 kg of K_2O ha^{-1} topdressing for radish. However, yield increased even at twice the recommended dose. According to Fernandes (2006), the excess of potassium fertilizer can cause nutritional imbalance, difficulty in absorbing water and other nutrients by saline effect, and impair production and quality. However, fertilization recommendations may be out of date, mainly because hybrids with higher productive potential and, consequently, greater need for nutrients have been used, as in the current research. Some authors have observed an increase in yield with K doses in a range above that recommended in different vegetables, such as pumpkin (Araújo et al., 2012), beetroot (Römheld and Kirkby 2010; Magro et al., 2015) and carrot (Zanfirov et al., 2012). However, there are also reports that K fertilization does not affect yield in other vegetables, such as zucchini (Araújo et al., 2013), cauliflower (Godoy et al., 2012), pea (Salata et al., 2011) and cabbage (Corrêa et al., 2013). However, all these authors justified the absence of results due to the high potassium content in soil, which was not the case in the current research, where it was considered medium content.

K was the most accumulated nutrient in the root of radish, and this result is also seen in other storage roots, such as beet (Magro et al., 2017) and carrot (Zanfirov et al., 2012). The higher absorption is related to the increase of the photosynthetic rate, the meristematic growth, sugar translocation and water use (Taiz and Zeiger 2013); being evident its importance for plants which store up reserves as radish.

The ability of a plant to obtain sufficient amounts of a particular nutrient for its growth and development may depend not only on the content or form available in the soil, but also on other factors that may affect its absorption (Marschener, 1995). The application of one nutrient may benefit or impair the content or action of the other, so the increase in potassium content in the soil reduces the absorption of magnesium by plants (Yamada and Roberts 1995), a fact that was not observed in the current study. Therefore, higher doses of potassium, which was applied within planting (organic compound and mineral fertilizer) and topdressing, could have caused a nutritional imbalance in the plant, which reflected in the increase of the magnesium absorption by the root.

One of the main nutrients that effectively acts on the quality and process of root formation is boron, since it participates in cell stretching and growth (Josten and Kutschera 1999). Within root development boron is involved in the control of enzymes linked to the metabolism of carbohydrates, phenols, lignin, auxins and nucleic acids (Lewis, 1980). Thus, B is directed linked to root growth, since there is intense formation of new tissues increasing the hormonal activity and energy expenditure (carbohydrates) for the growth and cellular division. Although it was the least exported micronutrient in plants, boron plays a major role in the formation of chlorophyll, protein synthesis and photosynthesis, as well as exerting a positive influence on disease resistance (Taiz and Zeiger 2013). It is worth emphasizing the fundamental role of this micronutrient in the formation of the cell wall, helping the deposition of calcium in these tissues, contributing to increase the resistance of plants to adverse effects, such as pest and disease attack, particularly the cracking of radish roots, such problem is responsible for major breakdowns by producers.

Materials and methods

Location and soil classification

The experiment was carried out at São Manuel Experimental Farm (FCA-UNESP), located at 22°44'28"S, 48°34'37"W and 740m above sea level. According to Köppen climate classification, São Manuel is Cwa, that is, humid subtropical climate and rainfall concentrated from November to April (summer), with average annual of 1376.70mm and average highs rarely exceed 22°C (Cunha and Martins 2009).

The soil is classified as Distrophic red latosol. Soil analysis was carried out to verify experimental area fertility; therefore, 45 days before planting, 10 subsamples were collected at a depth of 0-20 cm. The initial chemical characteristics of the soil were: pH ($CaCl_2$)=5.6; O.M=9 g dm^{-3}; $P_{(resin)}$=88 mg dm^{-3}; H + Al=18 mmol dm^{-3}; K=2 mmol dm^{-3}; Ca=33 mmol dm^{-3}; Mg=10 mmol dm^{-3}; SB=45mmol dm^{-3}; CTC=63 mmol dm^{-3}; V=71%. Based on result, soil is medium in content of potassium; this indicating good conditions for radish development with no need for further correction (Trani et al., 1997).

Plant materials and experimental design

The experiment was conducted in a randomized complete block design with five treatments and five replicates. Treatments corresponded to five doses of potassium (K_2O) topdressing, in the form of potassium chloride (KCl), being: T1 - 0 kg ha^{-1}; T2 - 22.5 kg ha^{-1}; T3 - 45 kg ha^{-1}; T4 - 67.5 kg ha^{-1}; T5 - 90 kg ha^{-1}, splitting applications at 7, 14 and 21 days after sowing, following the recommendation by Bulletin issue 100 (Trani et al., 1997). In addition, nitrogen (N) was applied in the form of urea (at 45 kg ha^{-1}) in all treatments. The recommendation of K_2O for radish culture is 45 kg ha^{-1}, but treatments were equivalent to 0, 50, 100, 150 and 200% of such recommendation (Trani et al., 1997).

For planting fertilization, 40 t ha^{-1} of the organic compound Provaso® and 902 kg ha^{-1} of NPK mineral fertilizer (04-14-08) were incorporated in the soil, according to Bulletin issue 100 (Trani et al., 1997). Thus, fertilization was applied proportionally in the plots (2.0 x 1.2m), being composed by 7 lines, respecting 15cm line-to-line spacing. Chemical analysis was previously performed on organic compound Provaso®, in total contents: 0.7% N; 0.7% P_2O_5; 0.2% K_2O; 2.1% Ca; 0.2% Mg; 0.2% S; 30% U (65°C); 19% O.M.; 11% C; Na-854 mg kg^{-1}; B-75 mg kg^{-1}; Cu-62 mg kg^{-1}; Fe-7525 mg kg^{-1}; Mn - 368 mg kg^{-1}; Zn - 274 mg kg^{-1}; C/N-16/1 and 6.7 pH; such analysis reported low potassium content.

Plant materials

Rafina hybrid was used and it is characterized by uniform roots, round shape, medium to large size and high isoporization resistance. Sowing was directly in field and thinning kept the spacing of 8cm between plants. For evaluations, three central lines were considered, totalling a useful area of 1.5 m^2 per plot, being disregarded borders, two adjacent lines and 30 cm within parcel divisions. During crop cycle, manual weeding and sprinkler irrigation were daily performed.

Measurements

Harvesting was performed 34 days after sowing, then roots were analyzed for: plant height (cm); transverse diameter (mm) and root length (mm); shoot fresh mass (g); root fresh mass (g); total fresh mass (g); shoot dry mass (g); root dry mass (g) and total dry mass (g), being all dried in an oven with forced air circulation at 65ºC, until reaching constant mass; commercial roots percentage and yield (t ha^{-1}).

Considering radish shoots and roots, 10 samples per plot were used to obtain both macronutrients (N, P, K, Ca, Mg and S) and micronutrients (B, Cu, Fe, Mn and Zn), following the methodology described by Malavolta et al. (2006), where nutrient accumulated in each sample were obtained by content proportion of each nutrient and sample dry mass.

Statistical analysis

Data were submitted to analysis of variance; and regression, when there was a significant difference (5% probability) in relation to the potassium doses, using the statistical program SISVAR 5.3 (Ferreira, 2010).

Conclusion

The current study inferred that the dose of 90 kg of K_2O ha^{-1} provided higher plant height (21.5cm), root fresh mass (40.4 g), total fresh mass (115.2 g), yield (33.7 t ha^{-1}), Mg concentration in the roots (2.9 mg $plant^{-1}$), and B in the leaves (3.6 mg $plant^{-1}$). The decreasing order of macro and micronutrient accumulation in the shoots was: N> P> K> Ca> S> Mg and Fe> Zn> Mn> Cu> B, respectively. The decreasing order of macro and micronutrient accumulation in the roots was: K> P> N> Ca> S> Mg and Fe> Zn> Mn> Cu> B, respectively.

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