horticultura brasileira

Research

TORRES, JLR; SILVA, GG; CHARLO, HCO; LOSS, A; LEMES, EM; VIEIRA, DMS. 2022. Lettuce crop fertilized with organomineral source of phosphorus and micronutrients. *Horticultura Brasileira* 40: 393-402. DOI: http://dx.doi.org/10.1590/s0102-0536-20220407

# Lettuce crop fertilized with organomineral source of phosphorus and micronutrients

**José Luiz R Torres [1]; Guilherme G da Silva [1]; Hamilton César de O Charlo [1]; Arcângelo Loss [2]; Ernane M Lemes [3]; Dinamar Márcia da S Vieira [3]**

[1]Instituto Federal do Triângulo Mineiro (IFTM), Uberaba-MG, Brasil; jlrtorres@iftm.edu.br (author for correspondence); guihguaira@gmail.com; hamiltoncharlo@iftm.edu.br; [2]Universidade Federal de Santa Catarina (UFSC), Florianópolis-SC, Brasil; arcangelo.loss@ufsc.br; [3]Universidade Federal de Uberlândia (UFU), Uberlândia-MG, Brasil; ernanefito@gmail.com; marcinha_0202@hotmail.com

## ABSTRACT

The use of organomineral fertilizers (OF) in the cultivation of vegetables has been considered a promising technology to provide nutrients gradually. The OFs can reduce the phosphorous (P) soil adsorption and leaching of nitrogen and potassium with the supply of some micronutrients. This study aimed to evaluate doses of OF as a source of P and micronutrients (boron and zinc) for curly lettuce cultivation. Five OF doses were evaluated: T1 = 0% (no $P_2O_5$ fertilization); T2 = 50% (75 mg/dm$^3$ of $P_2O_5$); T3 = 100% (150 mg/dm$^3$ of $P_2O_5$); T4 = 150% (225 mg/dm$^3$ of $P_2O_5$); T5 = 200% (300 mg/dm$^3$ of $P_2O_5$) of the lettuce recommended fertilization; T6 = 100% mineral fertilizer (MF) (150 mg/dm$^3$ of $P_2O_5$). The fresh (FM) and dry mass (DM) of the lettuce shoot (aerial part), the soil nutrient level, and the plant nutritional status at harvest were evaluated. We observed that (i) the doses of 225 and 300 mg/dm$^3$ of $P_2O_5$ via OF provided the same availability of P in the soil as the dose of 150 mg/dm$^3$ of $P_2O_5$ of MF; (ii) the doses of 225 and 300 mg/dm$^3$ of $P_2O_5$ of OF provided higher levels of soil boron and zinc compared to other treatments and (iii) the MF fertilization was more efficient than that of OF in the production of curly lettuce in a protected environment.

**Keywords:** *Lactuca sativa*, mineral fertilization, soil fertility, crop productivity.

## RESUMO

**Cultivo de alface sob diferentes doses de organomineral como fonte de fósforo e micronutrientes**

A utilização dos fertilizantes organominerais no cultivo das hortaliças vem sendo considerada como uma das tecnologias promissoras para fornecer nutrientes de forma lenta e gradual, diminuindo os problemas com adsorção de fósforo e lixiviação de nitrogênio e potássio, com fornecimento de alguns micronutrientes. Neste estudo objetivou-se avaliar o uso de diferentes doses de fertilizante organomineral (FO) como fonte fósforo (P) e micronutrientes no cultivo da alface crespa. No delineamento de blocos ao acaso, foram avaliadas cinco doses de FO: T1 = 0,0% (sem adubação com $P_2O_5$); T2 = 50% (75 mg/dm$^3$ de $P_2O_5$); T3 = 100% (150 mg/dm$^3$ de $P_2O_5$); T4 = 150% (225 mg/dm$^3$ de $P_2O_5$); T5 = 200% (300 mg/dm$^3$ de $P_2O_5$) da dose recomendada para a cultura, mais um tratamento adicional: T6 = adubação 100% fertilizante mineral (FM) (150 mg/dm$^3$ de $P_2O_5$), todos com 4 repetições. Avaliou-se a matéria fresca (MF) e seca (MS) da parte aérea das plantas de alface, o teor de nutrientes no solo e o estado nutricional na planta no momento da colheita. Observou-se que as doses de 225 e 300 mg/dm$^3$ de $P_2O_5$ via FO proporcionaram a mesma disponibilidade de P no solo que a dose de 150 mg/dm$^3$ de $P_2O_5$ de FM; as doses de 225 e 300 mg/dm$^3$ de $P_2O_5$ de FO proporcionaram teores superiores de boro e zinco no solo, em relação aos outros tratamentos utilizados; A adubação com FM se mostrou mais eficiente que a de FO na produção da alface crespa em ambiente protegido.

**Palavras chave:** *Lactuca sativa*, fertilizante mineral, fertilidade do solo, produtividade da cultura.

**Received on April 8, 2022; accepted on October 10, 2022**

Lettuce (*Lactuca sativa*) is one of the leading fresh vegetables consumed in salads and fast food, occupying an important position among vegetables with its significant economic and social importance. Lettuce is a short-cycle crop and a very demanding plant species regarding soil fertility and uses high amounts of mineral fertilizers to meet its needs (Queiroz *et al*., 2017). Thus, in lettuce cultivation, large nutrient intakes happen in relatively short periods, needs that are usually met using mineral fertilizers. Organic matter (OM) from cattle, poultry and other organic compounds supplement the fertilizing in vegetable production (Ribeiro *et al*., 2019).

New technologies have been developed to increase sustainability in vegetable cultivation; among them, organomineral fertilizers (OFs) seem to be very promising. Organominerals result from the physical mixing of different sources of organic matter (OM) with mineral fertilizer in the same fertilizer granule (Vieira *et al*., 2020). The use of OFs has stood out as an efficient way to provide nutrients associated with organic matter in relation to exclusive mineral sources (Smith *et al*., 2020).

OFs are produced from the enrichment of organic fertilizers with mineral fertilizers (MFs), making the OFs more agronomically efficient than the exclusive application of MFs or organic fertilizers alone (Luz *et al*., 2010). The authors also indicated that OFs increased yield and improved the production quality, as the OFs reduced the rate of mineralization, nutrient fixation, and leaching. The OM in the OF granule influences the exchange, sorption, adsorption, and solubilization reactions, as it serves as a direct source of nitrogen (N), phosphorus (P), sulfur (S) and some metals through its mineralization. According to Fernandes *et al*. (2015), this OF presents gradual solubilization, which allows the slow release of nutrients throughout the crop cycle.

Also, the OF is a source of carbon and energy for microorganisms and hinders the leaching of nutrients with high mobility in the soil, such as N, potassium (K) and boron (B), besides providing essential micronutrients (Yuri *et al*., 2004; Pol & Nogaroli, 2020). The knowledge about the dynamics of nutrient mineralization is important to synchronize the availability of soil nutrient and nutritional demands of the plant. This synchronism is intended to avoid the immobilization or rapid mineralization of nutrients such as P in high or low plant demand periods. Phosphorus is an essential macronutrient that frequently has limited agricultural availability under tropical conditions. The tropical soils present the total P level ranging from 200 to 3,000 mg/kg, and from 0.002 to 2.0 mg/L is found in the soil solution (Novais & Smyth, 1999).

The lack of P in the lettuce plant cycle is highly detrimental to its development (Kano *et al*., 2011; Marschner, 2012). With the potential reduction of nutrient losses by its slow release to soil solution, the OF rise as an option to improve the supply of plant needs throughout the cycle (Rodrigues *et al*., 2016). However, it is still necessary to clarify whether the slow release of nutrients provided by OFs can compensate for the increased OF doses and provide productivity compatible with those supplied by mineral fertilizers for lettuce. In this context, the objective of this study was to evaluate the use of different doses of OF as a P and micronutrient source in lettuce cultivation.

## MATERIAL AND METHODS

The experiment was implemented in the experimental area of the Federal Institute of the Triângulo Mineiro (IFTM), Campus Uberaba (19º39'19"S, 47º57'27"W, 800 m altitude). In an arc-type greenhouse, pots (6 $dm^3$) were filled with Oxisol (Santos *et al*., 2018) collected at 0-0.2 m soil depth, in the period between October and December, 2019.

The soil is a sandy loam presenting: 210 g/kg clay, 80 g/kg silt, and 710 g/kg sand. The soil chemical analysis presented: pH ($H_2O$)= 5.3; P= 3.8 mg/$dm^3$; K= 7 $mmol_c/dm^3$; Ca= 5 $mmol_c/dm^3$; Mg= 2 $mmol_c/dm^3$; Al= 3 $mmol_c/dm^3$; H+Al= 42 $mmol_c/dm^3$; organic matter = 0.031 g/kg; organic carbon = 0.017 g/kg; CTC= 56 $mmol_c/dm^3$, SB= 14 $mmol_c/dm^3$; base saturation (V)= 25%.

According to updated Köppen classification, the region's climate is Aw (warm tropical) (Beck *et al*., 2018), having hot and rainy summers and cold and dry winters. The annual precipitation, temperature, and relative humidity averages are about 1600 mm, 22.6ºC, and 68%, respectively (Inmet, 2021).

The randomized block design was the experimental plan to evaluate the treatments, which consisted of five doses of OF based on the recommended dose of P for lettuce cultivation (Ribeiro *et al*., 1999): T1 = 0% (no $P_2O_5$ fertilization); T2 = 50% (75 mg/$dm^3$ of $P_2O_5$); T3 = 100% (150 mg/$dm^3$ of $P_2O_5$); T4 = 150% (225 mg/$dm^3$ of $P_2O_5$); T5 = 200% (300 mg/$dm^3$ of $P_2O_5$), and T6 = 100% mineral fertilization (150 mg/$dm^3$ of $P_2O_5$). All treatments were replicated 4 times (*n* = 24), and each replication was the average of the evaluation of 6 pots (6 $dm^3$ each), totaling 144 pots.

The soil was sieved (2 mm side), then lime was applied (36.4% calcium oxide, 14% magnesium oxide, 99.87% neutralizing powder, 90.28% neutralizing powder relative total, to increase V to 70%, in all vessels in the experiment. The soil mixed with the limestone was placed in plastic bags (maintaining 6 $dm^3$ pot volume) and then placed inside its respective pot. The soil was moisturized, and the pots were kept in a greenhouse for 30 days for a complete limestone reaction. After this period, the treatments were incorporated into the soil and then transferred to their respective pots.

The OF was based on sugarcane filter cake and corresponded to a 6-24-8 (percentages of N-$P_2O_5$-$K_2O$, respectively) mineral fertilizer containing 0.1% B, 3% silicon (Si), 0.4% zinc (Zn), and 8% total organic carbon (TOC). The P doses were fixed, and the N (urea) and K (KCl) fertilization was supplemented so that all treatments received the same fertilization and matched 75 mg/$dm^3$ (150 kg/ha of N) and 100 mg/$dm^3$ (200 kg/ha of K) of the highest OF treatment dose (T5).

In the T1 treatment, no P was added, while in the T2 (50%), T3 (100%), T4 (150%), and T5 (200%) treatments, 1.87, 3.75, 5.63, and 7.5 grams of the OF was applied in each 6 $dm^3$ vase respectively. In T6 treatment, a 100% mineral fertilizer dose (150 mg/$dm^3$ of $P_2O_5$, corresponding to 300 kg/ha) was used throughout fertilization with triple superphosphate, according to soil analysis and crop need (Ribeiro *et al*., 1999). Two top dressing fertilizations of 25 mg/$dm^3$ N were applied at 15 and 30 days after lettuce seedling transplantation to the pots, totaling 50 mg/$dm^3$ of N applied.

Organomineral and mineral fertilizers were mixed into the soil before seedling transplant. The curly lettuce seedlings (Vanda cultivar presenting 4 to 5 expanded leaves) were transplanted to the center of each pot 7 days after the pot filling. After transplantation, the lettuce seedlings were irrigated daily by a dripping system which was calibrated to keep the soil to its water field capacity.

The lettuce harvest occurred 45 days after seedling transplantation. The plant shoots (aerial part) were cut close to the soil level and immediately proceeded with the determination of the fresh mass (FM) using a digital analytical balance. The harvested plants (shoots) were packed in paper bags and placed in a forced-air circulation oven at 65°C for 72 hours or until it reached constant mass to determine the lettuce (shoot) dry mass (DM).

The dry samples were crushed and taken to the Chemical Analysis Laboratory. Total N was determined by the Kjeldahl distillation method, P by colorimetry, and K by spectrophotometry of atomic immersion (Teixeira *et al*., 2017). Calcium (Ca) and magnesium (Mg) were determined by spectrophotometry of atomic absorption and sulfur (S) by turbidimetry (Tedesco *et al*., 1995). The micronutrients were determined according to Teixeira *et al*. (2017).

The values of the evaluated characteristics were submitted to the analysis of variance by applying the *F* test, and, when significant, submitted to regression analysis of quantitative factors (doses). The means of qualitative factors were compared by the Tukey test ($p<0.05$). The contrast between the means of each OF dose and the MF was performed by Dunnett's test ($p<0.05$), using the Agroestat® statistical program.

## RESULTS AND DISCUSSION

The lettuce FM of the 100% MF (150 mg/dm$^3$ of $P_2O_5$) presented a higher result (205.8 g/plant) when compared to the FMs observed for the other treatments (OF doses), which were 8.4; 60.4; 72.0; 101.1 and 108.5 g/plant, for doses of 0; 75; 150; 225 and 300 mg/dm$^3$ of $P_2O_5$, respectively. The lettuce FM at 100% MF was 65% higher than the dose of 100% OF (150 mg/dm$^3$ of $P_2O_5$) and 89% higher than the 200% OF dose (300 mg/dm$^3$ of $P_2O_5$). The lowest lettuce FM (8.4 g/plant) was observed when no OF was applied (T1 treatment).

This higher FM production of the MF treatment is due to its high solubility and fast nutrient availability for plant absorption, especially P. The P is slowly and gradually released from the OF as the lettuce crop cycle is short, and the plant cannot absorb the necessary P nutrition for its development. Similar results were observed by Vieira *et al*. (2020), where the highest lettuce FM yields occurred for the MF treatment. The authors also justified the results due to the short lettuce cycle, indicating that the lettuce plant needs P at a faster rate of reposition into the soil solution to develop normally.

In their study, Ribeiro *et al*. (2019) observed that fertilization with bovine and poultry manure was more efficient than mineral fertilization to the production of curly lettuce and provided greater P residual effects in the soil. The authors used 144% of the exclusively organic fertilizer (wet basis) corresponding to 72 t/ha of bovine manure and 29 t/ha of poultry manure compared to the recommended mineral fertilization (150, 400, and 60 kg/ha of N, $P_2O_5$, and $K_2O$, respectively).

Evaluating the use of organic and mineral fertilization in the cultivation of American lettuce, which has a longer crop cycle than curly lettuce, Trentini & Hojo (2019) highlighted that the organic and mineral combination presented improved effects. The authors observed that organic fertilizers improved the organic matter levels, favoring the soil's biological activity and physical aspects. In contrast, mineral fertilizers improved rapid plant growth and thus provided better conditions for crop development.

Oliveira Junior *et al*. (2020) observed that the total lettuce FM varied between 151 and 232 g/plant for the 400 cm$^3$ container, while Borges *et al*. (2020) observed 199 to 299 g/plant for curly lettuce and 188 to 292 g/plant for purple lettuce. Those FM values are close to the results observed in the present study for the MF and are at least 50% above the

**Table 1.** Soil chemical attributes as a function of the $P_2O_5$ doses applied as organomineral fertilizer (OF) and mineral fertilizer (MF). Uberaba, IFTM, 2020.

| $P_2O_5$ doses | pH | P | K | Ca | Mg | H + Al | OF | MF |
|---|---|---|---|---|---|---|---|---|
| (mg/dm$^3$) | | (mg/dm$^3$) | (mmol$_c$/dm$^3$) | | | | (g/kg) | |
| 0 (OF) | 6.1 | 6.2 b+ | 3.2 d+ | 30.4 c+ | 13.5 b+ | 13.3 b+ | 0.021 a+ | 0.012c+ |
| 75 (OF) | 6.0 | 6.9 b+ | 4.5 c | 33.4 b+ | 11.0 c+ | 13.0 b+ | 0.021 a+ | 0.011 c+ |
| 150 (OF) | 5.9 | 7.9 b+ | 8.9 a+ | 28.7 c+ | 13.5 b+ | 13.5 b+ | 0.023 a+ | 0.019 a+ |
| 225 (OF) | 6.0 | 14.4 a | 7.3 b+ | 26.8 c+ | 10.5 c+ | 13.3 b+ | 0.017 b+ | 0.010 c+ |
| 300 (OF) | 6.0 | 15.1 a | 5.2 c | 24.4 c+ | 11.0 c+ | 13.0 b+ | 0.025 a+ | 0.014 b+ |
| 150 (MF) | 5.8 | 12.4 a | 5.4 c | 40.3 a | 18.2 a | 17.0 a | 13.5 c | 7.8 d |
| F test | 0.50$^{ns}$ | 18.86$^{**}$ | 39.45$^{**}$ | 9.64$^{**}$ | 17.21$^{**}$ | 74.20$^{**}$ | 8.86$^{**}$ | 19.36$^{**}$ |
| LR | ns | 42.93$^{**}$ | 38.64$^{**}$ | ns | ns | ns | ns | ns |
| QR | ns | 13.17$^{**}$ | 83.82$^{**}$ | ns | ns | ns | ns | ns |
| CV (%) | 3.54 | 15.03 | 9.77 | 10.26 | 9.33 | 2.25 | 11.68 | 11.86 |

LR and QR = linear and quadratic regression. CV (%) = coefficient of variation. ns = not significant ($p>0.05$). ** = significant at 5% probability. Averages followed by same letters in the column do not differ by Tukey's test ($p<0.05$). + = OF treatment that differs from MF treatment by Dunnett's test ($p<0.05$).

**Table 2.** Macronutrient and micronutrient level in lettuce leaves as a function of the $P_2O_5$ doses applied as organomineral fertilizer (OF) and mineral fertilizer (MF). Uberaba, IFTM, 2020.

| $P_2O_5$ doses | N | P | K | Ca | Mg | S | B | Zn |
|---|---|---|---|---|---|---|---|---|
| ($mg/dm^3$) | (g/kg) | | | | | | (mg/kg) | |
| 0 (OF) | 33.2 | 1.8 c+ | 58.1 | 9.3 | 4.5 a+ | 1.7 b+ | 35.1 b | 22.1 d+ |
| 75 (OF) | 32.7 | 4.2 a+ | 50.3 | 8.0 | 3.7 b | 1.5 c | 41.0 b | 22.1 d+ |
| 150 (OF) | 35.2 | 4.5 a+ | 53.6 | 8.5 | 3.7 b | 1.5 c | 45.9 b | 25.0 c+ |
| 225 (OF) | 31.4 | 4.8 a+ | 51.1 | 10.4 | 3.8 b | 1.6 c | 103.1 a+ | 35.4 a+ |
| 300 (OF) | 30.9 | 4.8 a+ | 53.2 | 8.6 | 4.9 a+ | 2.0 a+ | 113.1 a+ | 24.6 c+ |
| 150 (MF) | 30.4 | 2.8 b | 47.3 | 8.1 | 3.2 b | 1.3 c | 39.3 b | 28.2 b |
| F test | $1.13^{ns}$ | $20.84^{**}$ | $1.99^{ns}$ | $2.66^{ns}$ | $8.76^{**}$ | $8.39^{**}$ | $39.13^{**}$ | $39.13^{**}$ |
| LR | ns | $75.58^{**}$ | ns | ns | $12.15^{**}$ | $18.29^{**}$ | $82.7^{**}$ | $82.7^{**}$ |
| QR | ns | $19.52^{**}$ | ns | ns | $12.174^{**}$ | $11.57^{**}$ | $27.2^{**}$ | $27.2^{**}$ |
| CV (%) | 8.99 | 12.40 | 8.56 | 10.91 | 9.18 | 8.40 | 5.51 | 5.51 |

LR and QR = linear and quadratic regression. CV (%) = coefficient of variation. ns = not significant ($p>0.05$). ** = significant at 5% probability. Averages followed by same letters in the column do not differ by the Tukey's test ($p<0.05$). + = OF treatment that differs from MF treatment by Dunnett's test ($p<0.05$).

value obtained for the highest OF dose (300 $mg/dm^3$ $P_2O_5$).

Regarding the lettuce DM, the values observed for doses 300, 225 and 150 $mg/dm^3$ of $P_2O_5$ of organomineral fertilizer were 6.4, 6.1 and 6.0 g/plant, respectively. Those values were higher ($p<0.05$) than the 100% of MF (150 $mg/dm^3$ of $P_2O_5$) and at zero doses (0.7 g/plant) and 75 $mg/dm^3$ of $P_2O_5$ (3.6 g/plant).

Studies conducted at this hottest time of the year, curly lettuce grown inside the greenhouse has greater transpiration due to the greater incidence of solar radiation, translating into photosynthesis and consequently greater production of fresh mass, which in turn, these same plants tend to accumulate less dry mass in the shoot, due to heat stress caused by high temperatures, as highlighted by Blat *et al*. (2011).

The lettuce cultivars Babá de Verão, Tainá and Verônica produced 8.9, 6.9, and 6.4 g/plant of DM when grown under field conditions in the semiarid region of Mossoró-RN (Brazil) and fertilized with bovine manure and mineral fertilizer (Grangeiro *et al*., 2006). Those values are similar to those observed for the 300, 225, and 150 $mg/dm^3$ $P_2O_5$ of the OF and higher than the 4.9 g/plant at the dose 150 $mg/dm^3$ of $P_2O_5$ of MF. The presence of the organic matter improved the increase of lettuce DM in both studies.

The regression analysis indicated a quadratic adjustment to the data for lettuce FM production, which increased up to 300 $mg/dm^3$ of $P_2O_5$ as OF; the lettuce DM regression also adjusted to a quadratic model; however, the lettuce DM production increased up to 219 $mg/dm^3$ of $P_2O_5$ per dose, reaching 6.3 g/plant (Figure 1).

The soil chemical attributes soon after the lettuce harvest indicated that 300 and 225 $mg/dm^3$ of $P_2O_5$ as OF and 150 $mg/dm^3$ of $P_2O_5$ as MF presented similar soil P level but superior results to the 150, 75, and 0 $mg/dm^3$ of $P_2O_5$ as OF (Table 1). These results evidence the need for more fertilizer applied when OF is used as P source to match the P availability in the soil when MF is used.

The 150 $mg/dm^3$ $P_2O_5$ as OF presented the highest K nutrient availability in the soil, reaching 8.9 $mmolc/dm^3$ of K, higher than the K availability of the other OF doses and the MF treatment. The organic matter present in the OF at 150, 225 and 300 $mg/dm^3$ of $P_2O_5$ probably attenuated the leaching losses and provided higher values of K in the soil in relation to the other doses of FO and the MF treatment.

However, Ca, Mg, H+Al and soil organic matter (OM) observed for all OF doses differ from the MF treatment (Table 1). The lower values observed for Ca, Mg, and H+AL in the OF doses are justified by the greater nutrient availability of the MF treatment, which alters the nutrient balance of the soil solution, while the higher values of OM and organic carbon are related to the OM present in the OF and the improved soil conditions for the soil microbiota development when OF is applied.

The regression analysis of the OF doses indicated a linear adjustment for P in the soil solution and $P_2O_5$ doses. The same did not occur for the K in the soil solution, where a quadratic adjustment indicated that the K level increased up to a dose of 177 $mg/dm^3$ of $P_2O_5$, reaching a maximum of 7.7 $mmolc/dm^3$ of K in the soil solution (Figure 2).

The results observed in the present study highlight the importance of applying P in a more readily available form for lettuce crop development. Thus, OF must be used in sufficient quantity to have an average plant growth and reach higher productions, as highlighted in other studies (Kano *et al*., 2011; Vieira *et al*., 2020).

The potential soil acidity (H+Al) was higher when MF was used. Factors such as rainfall volume (base leaching), crop nutrient extraction, ionic exchanges in the rhizosphere region, the acidity of

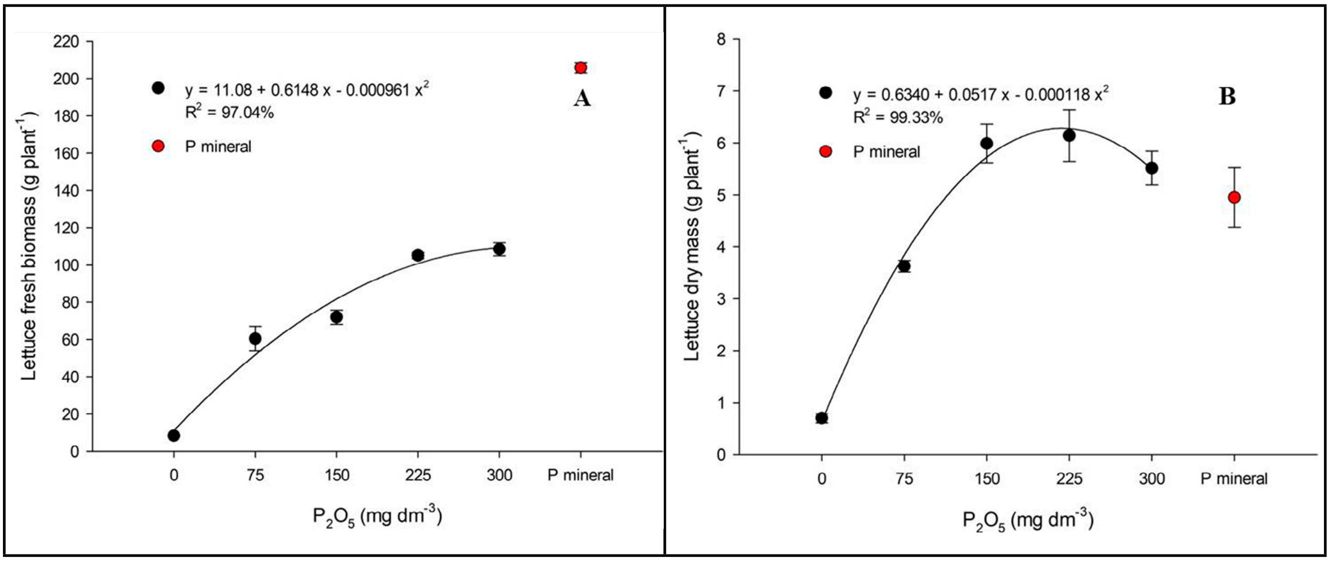


**Figure 1.** Fresh (left) and dry (right) lettuce mass as a function of the $P_2O_5$ doses applied as organomineral fertilizer. Uberaba, IFTM, 2020.

nitrogen fertilizers, and the soil origin alter the predominant soil acidity, which affects the dynamics of the nutrient's mineralization (Maluf *et al*., 2015). According to Oliveira *et al*. (2014), the dynamic of mineral nutrients and the potential soil acidity can be altered by adding different organic compounds, which favored the development of lettuce plants.

The P release from the OFs is usually slow and gradual due to its organic fraction. According to Fernandes *et al*. (2015), the justification for this slow release of the nutrient is related to competition for P adsorption sites and organic acids generated by the slow mineralization of organic matter added to the soil. Thus, there may be lower P availability at the beginning of the crop cycle and higher P availability in the soil at the end at the crop cycle (Vieira *et al*., 2020). These availability dynamics are especially important for short-cycle plants like lettuce, which required quick nutrient intake. The association of mineral nutrients with the organic matter fraction will also occur in Oxisols (Cerrado biome) by the blockade of the adsorption sites in Fe and Al oxides present in the soil. This blocking reaction reduces the soil adsorption capacity of P, which naturally occurs in more acidic soils (Novais & Smyth, 1999).

The macronutrient levels observed in lettuce leaves for N, K, and Ca were similar between the OF and MF treatments (Table 2). Those nutrients (N, K, and Ca) were within the sufficiency ranges: 30 to 50 g/kg for N, 50 to 80 g/kg for K, and 15 to 25 g/kg for Ca (Trani & Raij, 1997). Potassium is the most accumulated macronutrient by lettuce. Once in the plant, K remains in its ionic form ($K^+$), facilitating its concentration, transport, and redistribution within the plant tissues (Grangeiro *et al*., 2006; Marschner, 2012). However, Vieira *et al*. (2020) reported that lettuce plants from treatments including fertilization with organic compounds present higher levels of N, P, and K in their leaf tissues when compared to plants treated using only mineral fertilizer.

However, the same did not occur for P, Mg, and S. Phosphorus presented a similar leaf level among the OF doses (75, 150, 225, and 300 mg/dm³ of $P_2O_5$). Still, Mg presented a similar leaf level between the no-OF application (0 mg/dm³ of $P_2O_5$) and the application of 300 mg/dm³ of $P_2O_5$ as OF. The S leaf level was the greatest only when 300 mg/dm³ of $P_2O_5$ as OF was applied, and this was expected since organic fractions are usually good S sources (Lucheta & Lambais, 2012).

The regression analysis indicated a quadratic adjustment to the P lettuce leaf level and the OF doses. This adjustment indicated that the P leaf level increased up to 5 g/kg for the 220 mg/dm³ $P_2O_5$ dose as OF (Figure 3A). The soil P availability increases its absorption by the lettuce leaf up to 47% above the recommended dose (150 mg/dm³ $P_2O_5$).

It was expected that the highest level of P in lettuce leaf would occur at the highest OF dose (300 mg/dm³ of $P_2O_5$); however, this did not happen, probably due to the dilution effect of this nutrient in the plant. The dilution effect is characterized when the relative growth rate of the DM is higher than the relative absorption rate of the respective nutrient (Figure 3C). The most increased DM production occurred at 219 mg/dm³ of $P_2O_5$ dose equivalent of OF.

Pol & Nogaroli (2020) observed that the deficiency of macronutrients in lettuce, in general, causes short plant growth, purplish lower leaves, darkening and atypical leaf development, mild yellowing, few leaf emissions, among others. None of these deficiency symptoms were observed for the doses evaluated, except for the zero dose of P, where some nutrient deficiency symptoms were observed.

The Mg lettuce leaf level (Figure 3C) decreased to 3.6 g/kg, for an OF dose equivalent to 134 mg/dm³ of $P_2O_5$; after this dose, a gradual increase of the Mg level was observed up to the highest dose (300 mg/dm³ of $P_2O_5$).

This gradual increase in the Mg leaf level is related to the improved

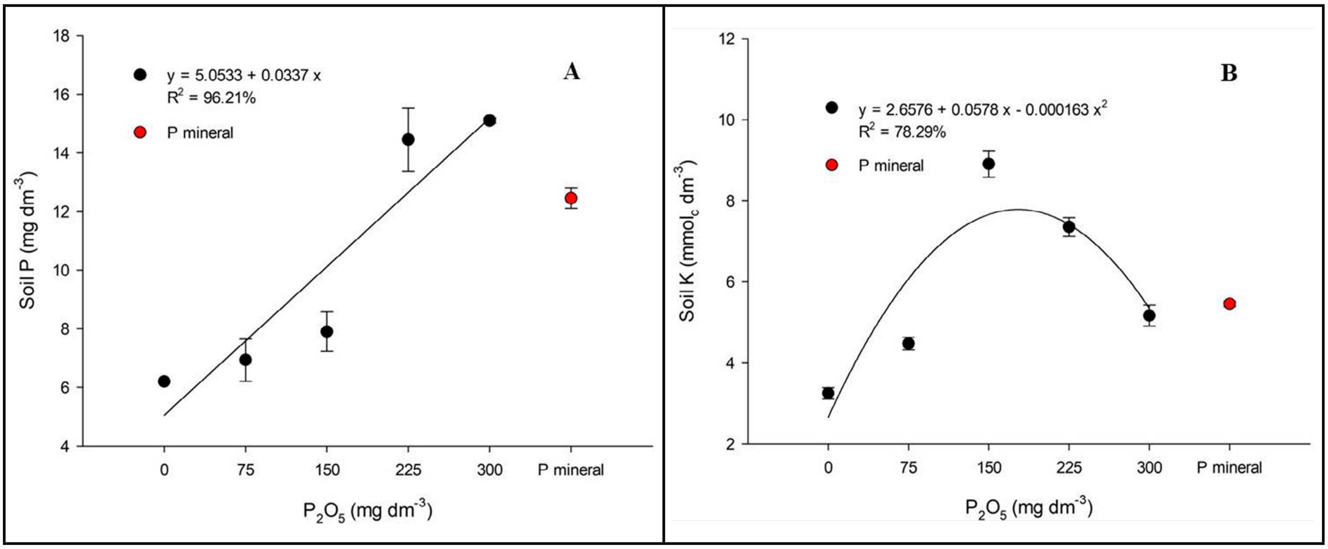


**Figure 2.** Phosphorus (P) (left) and potassium (K) (right) in the soil solution as a function of $P_2O_5$ doses applied as organomineral fertilizer. Uberaba, IFTM, 2020.

availability of this nutrient in the soil solution as the crop cycle evolves and the concentration effect of the nutrient in the plant tissue. Magnesium has numerous functions in plant's metabolisms, being present in chlorophyll, assisting in photosynthesis and cell energy production, and influencing the plants' absorption of P (Marschner, 2012); this same author highlights that there is an important synergism between P and Mg, although the mechanisms of this relationship are little known, it is known that Mg is a carrier of P, that the interactions between P and Mg are related to transfer reactions energy in the cell, in the activity of kinase enzymes and in phosphate transfer reactions, thus, its shortage during a crop cycle hinders the whole plant's development.

The S lettuce level (Figure 3E) also decreased to a minimum limit of 1.5 g/kg using 123 mg/dm$^3$ $P_2O_5$ as OF, increasing from that dose up to the 300 mg/dm$^3$ $P_2O_5$ as OF, when compared to the other doses evaluated. According to Oliveira *et al*. (2014) and Marschner (2012), factors that affect plant growth rates and absorption of nutrients will consequently lead to different nutrient levels in plant tissue. For example, if the plant growth rate is null and the nutrient continues to be absorbed, a nutrient concentration will occur; however, dilution will occur if plant tissue rapidly grows and the nutrient is absorbed in the same rate.

The regression analysis of P accumulation in the lettuce plant (Figure 3B) presented a pattern similar to that observed for P level in the leaf (Figure 3A). The highest P accumulation observed in lettuce was 31.1 g/kg for 257 mg/dm$^3$ $P_2O_5$ applied as OF. This accumulated P in the lettuce plant (31.1 g/kg) was over six times higher than the P level found in the lettuce leaf (5.0 g/kg).

In general, the amount of P required by the crops is low; especially when compared to N and K. However, if there was not enough P for the plant to absorb, there may be a delay in lettuce growth, head malformation, and death of young plants (Pol & Nogaroli, 2020). None of these indicators of P deficiency was observed in the lettuce plants of the present study.

Quadratic adjustments were observed for Mg and S level in the lettuce leaf (Figure 3C and 3E) and for the plant accumulation of these nutrients (Figure 3D and 3F) and increased with the increase of the OF dose used. A similar dynamic for Mg in lettuce was also observed by Grangeiro *et al*. (2006), which reported increased Mg accumulation in all evaluated lettuce cultivars.

The B lettuce leaf level of 225 and 300 mg/dm$^3$ of $P_2O_5$ doses as OF was higher than the level of B observed in the lettuce leaves treated with MF (Table 2). Boron is linked to cell growth, mainly in the newer regions of the plant and meristematic tissues (Marschner, 2012). In lettuce, the main symptom of B deficiency is low and plants develop purplish or light green leaves.

The levels of Zn for all OF doses were different from the level observed for the MF treatment, and only at the 225 mg/dm$^3$ of $P_2O_5$ dose, the leaf level of Zn was higher than all other doses evaluated (Table 2). Zinc is responsible for enzymatic activations and the control of growth regulators and also presents its main symptom of deficiency (necrosis) in the younger leaves (Marschner, 2012; Pol & Nogaroli, 2020). None of these indicators of B or Zn deficiency was observed in the lettuce plants of the present study.

The regression analysis of the B level in lettuce leaves indicated a slow increase up to 38.9 mg/dm$^3$, which is equivalent to the dose of 75 mg/dm$^3$ of $P_2O_5$ as OF (Figura 5A). For higher OF doses, the increase of the B level in the lettuce leaves was sharp until it reached its maximum peak at the highest OF dose (300 mg/dm$^3$ of $P_2O_5$) (Figure 4A).

The B accumulation in the lettuce plant adjusted to a linear model (Figure 4B), presenting a pattern similar to the

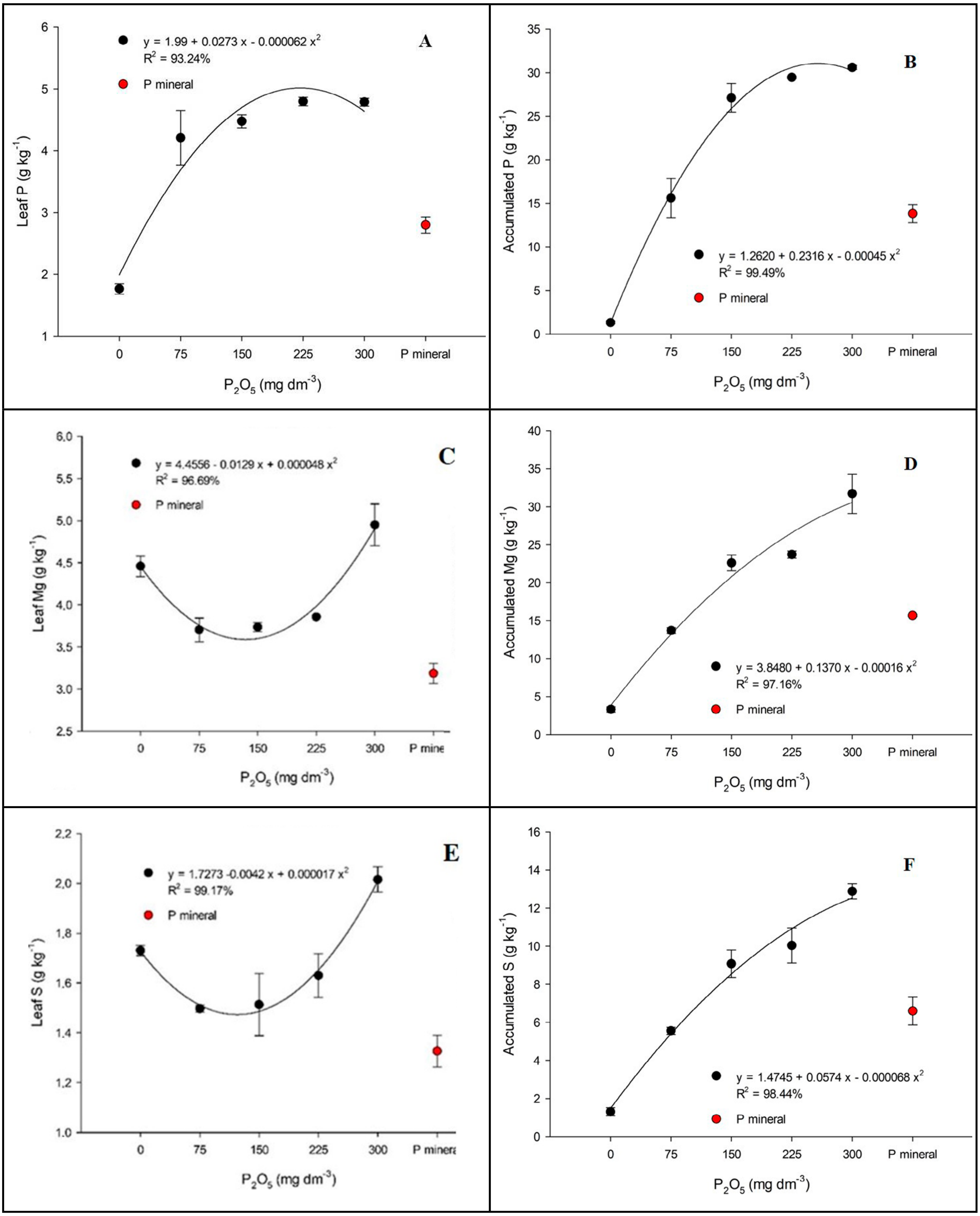


**Figure 3.** Phosphorus (P) (A), magnesium (Mg) (C) and sulfur (S) (E) content and accumulated P (B), Mg (D) and S (F) in lettuce leaves as a function of $P_2O_5$ doses applied as organomineral fertilizer. Uberaba, IFTM, 2020.

B lettuce leaf level (Figure 4A). These results indicated that the lettuce plant did not present any level of B deficiency, which is one of the micronutrients that most affect lettuce development, as it is an element that presents high mobility in the soil profile (Pol & Nogaroli, 2020). The application of 1.71 kg/ha of borax (11% soluble B) three weeks after transplanting improved commercial fresh mass (563 g/plant) of American lettuce (winter cultivation) (Yuri *et al.*, 2004).

The improved levels of B in the lettuce leaf can be related to the amount of OM applied by the OF. Bergamin *et al*. (2005) highlighted that in soils not fertilized with B, the organic matter is one of the most important sources of this nutrient, especially in sandy soils, generally acidic soils and poor in organic matter. According to Sinha *et al*. (2003), soils with low P levels also interfere with the B metabolism, aggravating the deficiency or toxicity symptoms.

The Zn level in lettuce leaves adjusted to a quadratic regression model, increasing up to 38.4 mg/kg, at the dose of 216 mg/dm$^3$ $P_2O_5$ as OF (Figure 4C); however, this adjustment presented a low coefficient of determination ($R^2$ = 46.13%). The accumulation of Zn in the plant also presented a quadratic adjustment (Figure 4D), with a determination coefficient of 92.28%. There was a maximum accumulation of 190 mg/kg of Zn for a 236 mg/dm$^3$ of $P_2O_5$ as OF.

This decrease in the accumulated values of Zn at the highest P doses applied in this study can be explained by the relationship between the nutrients, since Zn deficiency in the plant is associated with high levels of available P in the soil. Marschner (2012) cites some studies showing that Zn deficiency can be induced by the application of phosphate fertilizers, since excess P inhibits the translocation of Zn from the root to the shoot of the plant.

The leaf levels and accumulation of Zn by lettuce may vary depending on the amount of fertilizer applied, plant genotype, and stage of plant development. However, high doses of fertilizers containing Zn should be

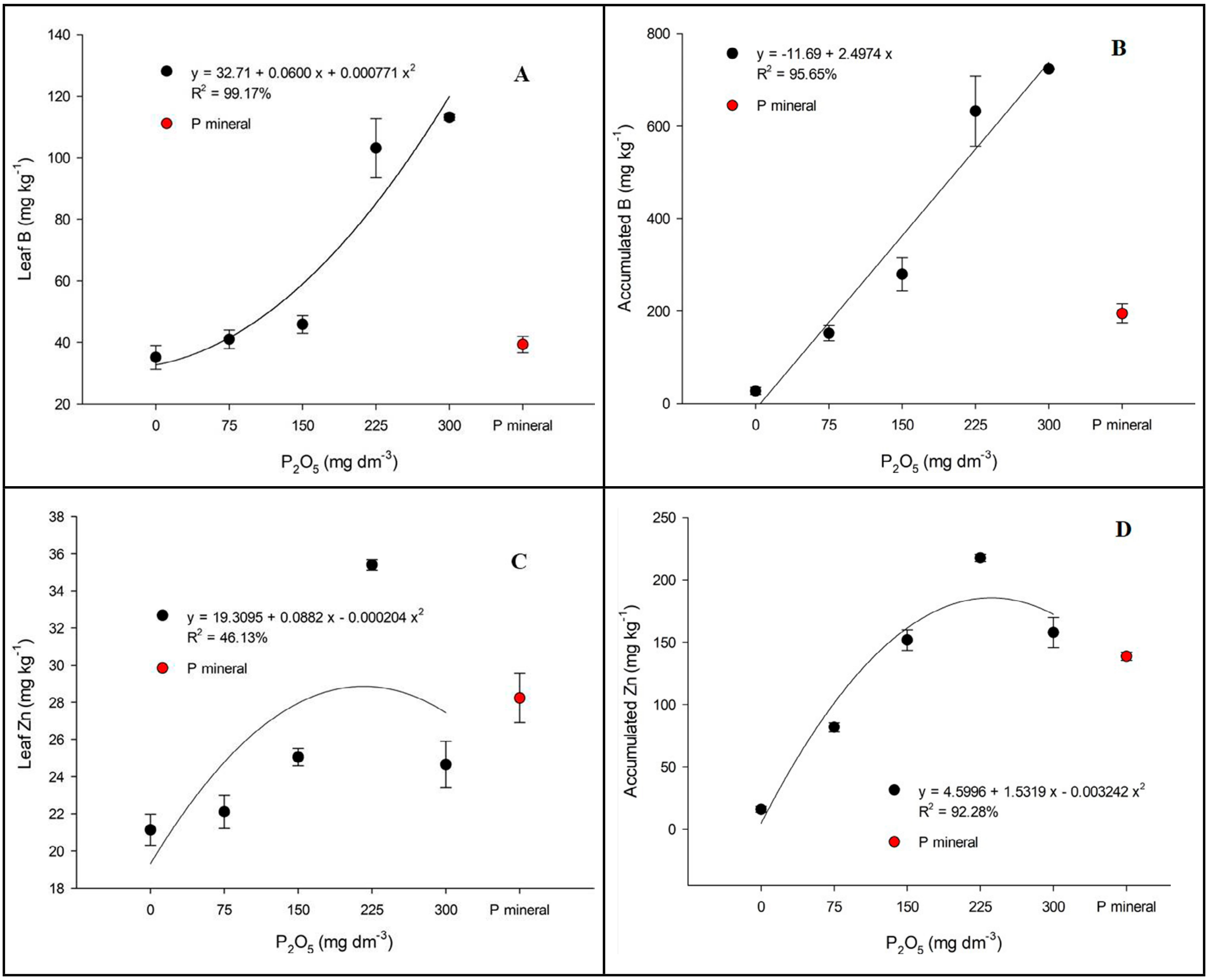


**Figure 4.** Boron (B) and zinc (Zn) lettuce leaf level (A and C) and accumulated in lettuce plants (B and D) as a function of $P_2O_5$ doses applied as organomineral fertilizer. Uberaba, IFTM, 2020.

avoided since Zn can easily cause plant toxicity and limit lettuce productivity and quality (Broadley *et al*., 2010). The doses of OF were insufficient to cause Zn toxic effects in the present study, whether for OF or MF treatments. Moraes (2020) observed that the accumulation of Zn by lettuce leaves increased 8.9 times due to the increase in Zn fertilizer doses; the author also highlighted that the levels of Zn in the leaves did not interfere with the accumulation of other nutrients in the plant.

Organomineral fertilizers are a viable and promising technology for plant nutrition delivery. The OF benefits to the soil and plant performance are well known (Smith *et al*., 2020), and such improvements could be observed in the present study. However, the sole use of OF as the source of most P and micronutrients to the cropping of curly lettuce is not recommended. The lower rate of nutrient mineralization in OFs hinders lettuce development due to its short crop cycle. The study and calibration of OFs is suggested for lettuce crops, complemented with the application(s) of mineral fertilizers to compensate the high lettuce plant demands in a short period.

The organomineral doses equivalent to 300 and 225 mg/dm$^3$ of $P_2O_5$ provided the same soil phosphorus availability as the mineral fertilizer (150 mg/dm$^3$ of $P_2O_5$).

All fertilizer treatments presented leaf lettuce levels of nitrogen, phosphorous, and potassium within crop sufficiency ranges for normal plant development. With regard to micronutrients, the organomineral doses equivalent to 300 and 225 mg/dm$^3$ of $P_2O_5$ provided higher levels of boron and zinc in the soil.

The results obtained in this study showed that fertilization with mineral fertilizer was more efficient than that of organomineral fertilizer for the production of crisp lettuce in a protected irrigated environment.

## ACKNOWLEDGMENTS

Thanks to The Instituto Federal do Triângulo Mineiro (campus Uberaba) for providing the experimental area, equipment, and laboratory to experiment development and sample analysis. To Fundação de Estudos Agrários Luiz de Queiroz (AGRISUS FOUNDATION), Minas Gerais Research Support Foundation (FAPEMIG), Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES), and Conselho Nacional de Desenvolvimento Científico e Tecnológico (CNPq) for scholarships granted to the students and project funding.

## REFERENCES

BECK, HE; ZIMMERMANN, NE; MCVICAR, TR; VERGOPOLAN, N; BERG, A; WOOD, EF. 2018. Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Scientific Data* 1: 1-12.

BERGAMIN, LG; CRUZ, MCP; FERREIRA, ME; BARBOSA, JC. 2005. Produção de repolho em função da aplicação de boro associada a adubo orgânico. *Horticultura Brasileira* 23: 311-315.

BORGES, EC; SCHMID, DM; SAUL, LT; SORDI, A. 2020. Produtividade de cultivares de alface (*Lactuca sativa* L.) em função de tipos de telas de sombreamento no município de Maravilha, SC. *Anuário Pesquisa e Extensão Unoesc São Miguel do Oeste* 5: 1-9.

BLAT, SF; SANCHEZ, SV; ARAÚJO, JAC; BOLONHEZI, D. 2011. Desempenho de cultivares de alface crespa em dois ambientes de cultivo em sistema hidropônico. *Horticultura Brasileira* 29: 135-138.

BROADLEY, MR; LOCHLAINN, SO; HAMMOND, JP; BOWEN, HC; CAKMAK, I; EKER, S; ERDEM, H; KING, GJ; WHITE, PJ. 2010. Shoot zinc (Zn) concentration varies widely within *Brassica oleracea* L. and is affected by soil Zn and phosphorus (P) levels. *Journal of Horticultural Science and Biotechnology* 85: 375-380.

FERNANDES, DM; GROHSKOPF, MA; GOMES, ER; FERREIRA, NR; BULL, LT. 2015. Fósforo na solução do solo em resposta à aplicação de fertilizantes fluidos mineral e organomineral. *Irriga* 1: 14-27.

GRANGEIRO, LC; COSTA, KR; MEDEIROS, MA; SALVIANO, AM; NEGREIROS, MZ; BEZERRA NETO, F; OLIVEIRA, SL. 2006. Acúmulo de nutrientes por três cultivares de alface cultivadas em condições do semiárido. *Horticultura Brasileira* 24: 190-194.

INMET – Instituto Nacional de Meteorologia. Gráficos. 2021. 08 de novembro. Available at http://www.inmet.gov.br/portal/index.php/gráficos

KANO, C; CARDOSO, AII; VILLAS BÔAS, RL. 2011. Acúmulo de nutrientes pela alface destinada à produção de sementes. *Horticultura Brasileira* 29: 70-77.

LUCHETA, AR; LAMBAIS, MR. 2012. Sulfur in agriculture. *Revista Brasileira de Ciência do Solo* 36: 1369-1379.

LUZ, JMQ; OLIVEIRA, G; QUEIROZ, AA; CARREON, R. 2010. Aplicação foliar de fertilizantes organominerais em cultura de alface. *Horticultura Brasileira* 28: 373-377.

MALUF, HJGM; SOARES, EMB; SILVA, IRS; NEVES, JCL; SILVA, MFO. 2015. Disponibilidade e recuperação de nutrientes de resíduos culturais em solo com diferentes texturas. *Revista Brasileira de Ciência do Solo* 39: 1690-1702.

MARSCHNER, H. 2012. *Mineral nutrition of higher plants*. 3 ed. London: Elsevier. 643p.

MORAES, CC. 2020. *Biofortificação agronômica com zinco em alface*. Campinas: IAC. 77p. (Ph.D. Thesis).

NOVAIS, RF; SMYTH TJ. 1999. *Fósforo em solo e planta em condições tropicais*. Viçosa: UFV. 399p.

OLIVEIRA JÚNIOR, PP; FERREIRA, RLF; ARAÚJO NETO, SE; SOUZA, LGS. 2020. Rendimento de alface em ambientes de cultivo utilizando mudas produzidas com volume crescente de substrato. *Scientia Naturalis* 2: 499-507.

OLIVEIRA, LB; ACCIOLY, AMA; SANTOS, CLR; FLORES, RA; BARBOSA, FS. 2014. Características químicas do solo e produção de biomassa de alface adubada com compostos orgânicos. *Revista Brasileira de Engenharia Agrícola e Ambiental* 18: 157-164.

POL, CH; NOGAROLI, JA. 2020. Omissão de nutrientes na cultura da alface (*Lactuca sativa* L.). *Revista Tuiuti: Ciência e Cultura* 6: 68-87.

QUEIROZ, AA; CRUVINEL, VB; FIGUEIREDO, KME. 2017. Produção de alface americana em função da fertilização com organomineral. *Enciclopédia Biosfera* 14: 1054-1063.

RIBEIRO, AC; GUIMARÃES, PTG; ALVAREZ, VVH. 1999. *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5°. Aprox*. Viçosa: UFV. 359p.

RIBEIRO, RR; TORRES, JLR; ORIOLI JUNIOR, V; CHARLO, HCO; VIEIRA, DMS. 2019. Growth analysis of green-leaf lettuce under different sources and doses of organic and mineral fertilization. *Revista Colombiana de Ciencias Hortícolas* 13: 237-247.

RODRIGUES, M; PAVINATO, PS; WITHERS, PJA; TELES, APB; HERRERA, WFB. 2016. Legacy phosphorus and no tillage agriculture in tropical oxisols of the Brazilian savanna. *Science of the Total Environment* 542: 1050-1061.

SANTOS HG; JACOMINE, PKT; ANJOS, LHC; OLIVEIRA, VA; LUMBRERAS, JF; COELHO, MR; ALMEIDA, JA; CUNHA, TJF; OLIVEIRA, JB. 2018. *Sistema brasileiro de classificação de solos*. 3° ed., Brasília, DF: Embrapa Informação Tecnológica, 356p.

SINHA, P; DUBE, BK; CHATTERJEE, C. 2003. Phosphorus stress alters boron metabolism of mustard. *Communications in Soil Science and Plant Analysis* 34: 315-326.

SMITH, WB; WILSON, M; PAGLIARI, P. 2020. *Organomineral fertilizers and their application to field crops*. IN: WALDRIP, HM; PAGLIARI, PH; HE, Z (eds). Animal Manure - Production, Characteristics, Environmental Concerns, and Management. ASA and SSSA: Madison. 67: 229-243.

TEDESCO, MJ; GIANELLO, C; BISSANI, CA; BOHNEN, H; VOLKWEISS, SJ. 1995. *Análise de solo, plantas e outros materiais*. Boletim Técnico 5, UFRGS, Porto Alegre. 174p.

TEIXEIRA, PC; DONAGEMMA, GK; FONTANA, A; TEIXEIRA, WG. 2017. *Manual de métodos de análise de solos*. 3.ed. rev. e ampl. Rio de Janeiro: Embrapa, 573p.

TRANI, PE; RAIJ, B. 1997. Hortaliças. In: RAIJ, B; CANTARELLA, H; QUAGGIO, JA; FURLANI, AMC (eds). *Recomendações de adubação e calagem para o estado de São Paulo*. Campinas: IAC, (Boletim técnico, 100), p.163.

TRENTINI, H; HOJO, ETD. 2019. Uso de adubação orgânica e mineral na produtividade de alface americana cv. Amélia. *Revista Cultivando o Saber* 1: 83-90.

VIEIRA, DMS; CAMARGO, R; TORRES, JLR; SILVA, AA; LANA, RMQ; CARVALHO, FJ. 2020. Growing vegetables in succession in different soils and doses of phosphorus in an organomineral fertilizer. *Revista Brasileira de Engenharia Agrícola e Ambiental* 24: 806-813.

YURI, JE; RESENDE, GM; MOTA, JH; RODRIGUES JÚNIOR, JC; SOUZA, RJ; CARVALHO, JG. 2004. Comportamento da alface americana em função do uso de doses e épocas de aplicação de boro em cultivo de inverno. *Horticultura Brasileira* 22: 593-596.