

Growth analysis of green-leaf lettuce under different sources and doses of organic and mineral fertilization

Análisis de crecimiento de lechuga crespa bajo diferentes fuentes y dosis de fertilización orgánica y mineral



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Experiment lettuce plant growth.

Photo: R.R. Rejane

ABSTRACT

The objective of this study was to evaluate the influence of different sources and doses of organic and mineral fertilization on the production of green-leaf lettuce. The experiment design used randomized blocks in a factorial scheme (6×3), with six doses of fertilizers (1 = 0; 2 = 25; 3 = 50; 4 = 100; 5 = 150, and 6 = 200% of the recommended fertilization for green-leaf lettuce crop) and three sources of fertilizers [cattle manure (CaM) and chicken manure (ChM), decomposed, on a wet basis and applied 100% at planting at the doses: CaM – 0, 12.5, 25, 50, 75, 100 Mg ha⁻¹; ChM – 0, 5, 10, 20, 30, 40 Mg ha⁻¹; mineral fertilization (MF) varying the N levels: 0, 37.5, 75, 150, 225, 300 kg ha⁻¹ plus 400 kg ha⁻¹ of P₂O₅ and 60 kg ha⁻¹ of K₂O]. The fertilization with CaM and ChM was more efficient than the MF at increasing the production of green-leaf lettuce, mainly because of the higher residual effects of P in the Oxisol. The ChM provided a higher soil pH, P and K, while the CaM provided a higher soil Mg, organic carbon and organic matter. The dose with 144% of organic fertilization exclusively on a wet basis corresponding to 72 Mg ha⁻¹ of CaM and 29 Mg ha⁻¹ of ChM resulted in the highest green-leaf lettuce yield.

Additional key words: *Lactuca sativa* L.; phosphorus; nitrogen; cattle manure; chicken manure.

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RESUMEN

El objetivo de este estudio fue evaluar la influencia de diferentes fuentes y dosis de fertilización orgánica y mineral en la producción de lechuga crespa. Se utilizó un diseño de bloques completos al azar, en un esquema factorial (6×3), donde se evaluaron seis dosis de fertilizante (1 = 0, 2 = 25; 3 = 50; 4 = 100; 5 = 150 y 6 = 200%) de la fertilización recomendada para la lechuga, tres fuentes de abono fertilizante (estiércol bonino (EB) y aves de corral (CP)), descompuesto, aplicado húmedo 100% en la siembra: 1 = EB - 0; 12,5; 25; 50; 75 y 100 Mg ha⁻¹; 2 = CP 0; 5; 10; 20; 30 y 40 Mg ha⁻¹; 3 = Fertilización mineral varió solo las cantidades de N; 3 = 0; 37,5; 75; 150; 225 y 300 kg ha⁻¹, junto a 400 kg ha⁻¹ de P₂O₅ y 60 kg ha⁻¹ de K₂O que se mantuvo en las parcelas con fertilización mineral. La fertilización con EB y CP demostró ser más eficiente que la fertilización mineral en la producción de lechuga crespa, principalmente debido a los mayores efectos residuales del P en el suelo. El estiércol CP proporcionó valores más altos de pH, P y K, mientras que el EB de Mg, materia orgánica y carbono orgánico en el suelo. La dosis del 144% de fertilizantes exclusivamente orgánicos en base húmeda correspondiente a estiércol de 72 Mg ha⁻¹ EB y 29 Mg ha⁻¹ CP, dieron los mejores rendimientos para la lechuga crespa en un Latosol.

Palabras clave adicionales: *Lactuca sativa* L.; fósforo; nitrógeno; estiércol de ganado; estiércol de aves.

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INTRODUCTION

Lettuce (*Lactuca sativa* L.) is the most cultivated leafy vegetable in Brazil. The States of São Paulo and Minas Gerais are the major producers, where green-leaf lettuce enjoys consumer preference, reaching 70% of the market, followed by American lettuce (15%), flat lettuce (10%) and 5% for other commercial types (Sala and Costa, 2012). In recent years, the consumption of processed lettuce has grown significantly, mainly serving fast-food restaurants, industries and hospitals (Mota *et al.*, 2012).

As a short cycle plant, lettuce uses high quantities of mineral fertilizers to meet plant development demands (Queiroz *et al.*, 2017), mainly for nitrogen (N). This nutrient is the most required macronutrient in horticultural crops; however, this nutrient presents great losses through leaching, volatilization, and immobilization, requiring special care in its management (Carvalho and Zabot, 2012).

The frequent increase in the cost of mineral fertilizers and increasing environmental pollution as a result of inappropriate agricultural activities highlight the use of organic fertilizers as an attractive option. Organic fertilizers are attractive for all farm sizes because of nutrient cycling and organic matter addition, which may modify a soil's physical, chemical and biological attributes, thus improving soil fertility (Pereira *et al.*, 2013). These potential effects of organic fertilizers

have generated new demands on researchers for assessing the technical and economic feasibility of such fertilizers (Melo *et al.*, 2008).

Agricultural activities produce plant and animal (manure) waste in large quantities, which has been used in agriculture for thousands of years but requires more efficient management in the fertilization of agricultural crops, mainly in vegetable crops with a short cycle (Figueiredo *et al.*, 2012; Vergel *et al.*, 2016). Knowledge on the dynamics of nutrient mineralization must be fully understood to improve nutrient availability in the soil of short-cycle crops, avoiding immobilization or rapid mineralization of nutrients during periods of high or low demand (Peixoto Filho *et al.*, 2013; Vaz *et al.*, 2019).

Bovine (cattle) manure (CaM) is widely used as an organic fertilizer for the production of vegetables. When this fertilizer is incorporated, it improves soil aeration and water absorption, as well as the chemical, physical and biological properties of the soil, generating a more balanced nutrient availability for plants (Cunha *et al.*, 2012). Abreu *et al.* (2010) emphasized that CaM has a water pH of 6.7, 26.9 g kg⁻¹ of organic matter, N, P, K, Ca, Mg and S at 11.4, 16.1, 8.3, 62, 13 and 6.7 g kg⁻¹; and B, Cu, Fe, Mn and Zn at 7.24, 67.8, 147, 146 and 119 mg kg⁻¹ (dry basis), respectively. However, this composition depends on

animal feed because, when done exclusively in pastures, these values are different than where there is supplementation with concentrates (Peixoto Filho *et al.*, 2013). In contrast, chicken manure (ChM) from intensive farming (poultry) is richer in nutrients, water pH of 8.4, 31.1 g kg⁻¹ of organic matter (OM), N, P, K, Ca, Mg and S at 32.2; 22.6, 30, 171, 8.9 and 6.9 g kg⁻¹; and B, Cu, Fe, Mn and Zn at 36.5, 69.6, 272, 583 and 631 mg kg⁻¹ of in dry basis, respectively (Abreu *et al.*, 2010).

In addition, manure fertilizers contain high levels of cellulose, which make residue decomposition and nutrient release slowly, generating positive consequences in vegetable crops (Souza, 2007). The contents of N, P and K in ChM are at higher concentrations than in other species of domestic animals since it contains 5 to 15% water, while other manures have 65 to 85% (Tedesco *et al.*, 2008). Using ChM as a form of fertilizer, Abreu *et al.* (2010) and Peixoto Filho *et al.* (2013) demonstrated that lettuce presented better root development and improved production of dry mass and yield when compared to other forms of organic fertilization.

The majority of studies assess the productivity of lettuce after the application of different sources of organic fertilization, but results vary according to the region, soil type and form of irrigation; however, only a few studies have assessed the residual effect of organic fertilization on the production of lettuce in the Cerrado biome. The objective of this study was to evaluate the influence of different sources and doses of organic and mineral fertilization on the production of green-leaf lettuce.

MATERIAL AND METHODS

The study was conducted in the experimental area of the horticulture sector of the Federal Institute of Triângulo Mineiro, Campus Uberaba, at the coordinates 19°45'27" S; 47°55'36" W, at an altitude of 764 m a.s.l. The experimental area was previously prepared with two harrowings, followed by a soybean cultivation cycle and two years without crop activities before the experiment was installed in the winter of 2017.

The climate of the region is characterized as tropical rainy, with a cold dry winter and hot humid summer - Aw climate type, according to Beck *et al.* (2018). The average annual precipitation and temperature are 1,600 mm and 22.6°C, respectively (Inmet, 2018); however, during the evaluation period, rainfall of 20 mm (June/2017) was recorded; the total accumulated in the year was 1,995.3 mm, above the normal for the region (Fig. 1).

The soil of the experimental area was classified as a dystrophic red latosol (Santos *et al.*, 2018), medium texture, presenting the following values in the 0-0.2 m layer four months prior to the liming: 210, 680 and 110 g kg⁻¹ of clay, sand and silt, respectively, pH (CaCl₂) 6.5; 20.9 mg dm⁻³ of P (Mehlich-1); 161 mg dm⁻³ of K⁺; 2.9 cmol_c dm⁻³ of Ca²⁺; 1.5 cmol_c dm⁻³ of Mg²⁺; 2 cmol_c dm⁻³ of H+Al and 18 g kg⁻¹ of organic matter and base saturation (V) of 71%.

The sowing of the green-leaf lettuce (Vanda cultivar, Sakata®) occurred in plastic trays (200 cells), grown under greenhouse conditions prior to field transplant.

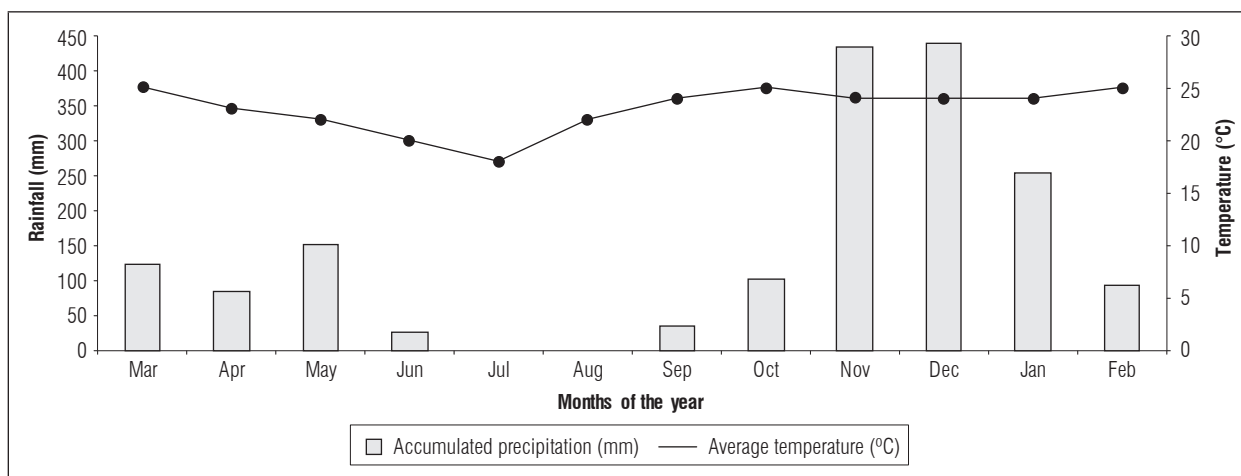


Figure 1. Climate variables obtained from the Meteorological Database for Teaching and Research (Inmet, 2018).

The seedlings were transplanted when they presented 4 to 6 final leaves that were completely expanded (7 to 10 cm height), approximately 25-30 days after sowing (DAS), and spaced 0.25 m between plants and between rows, in 4 planting rows, with 10 plants per row (40 plants per plot) in plots 1 m apart. The experiment plots were mechanically built and were 0.3 m tall, with 2.5×1 m (2.5 m²). In each plot, only 12 plants from the two central rows were evaluated.

The experiment design used the randomized block design in a 6×3 factorial scheme, with six doses of fertilizers (0, 25, 50, 100, 150 and 200% of the recommended fertilization for lettuce crop) and three fertilizers sources [cattle manure (CaM) and chicken (hens) manure (ChM), decomposed, on a wet basis and applied 100% at planting at the doses: CaM – 0, 12.5, 25, 50, 75, 100 Mg ha⁻¹; ChM – 0, 5, 10, 20, 30, 40 Mg ha⁻¹; mineral fertilization (MF) varying the N levels: 0, 37.5, 75, 150, 225, 300 kg ha⁻¹ of N as urea, plus 400 kg ha⁻¹ of P₂O₅ (superphosphate, 20% P₂O₅) and 60 kg ha⁻¹ of K₂O (KCl, 60% K₂O), as recommended in Ribeiro *et al.* (1999) – urea and KCl were fractionated: 20% at planting, 20, 20 and 40% in successive side-dressing fertilizations; all treatments had 4 replications (*n*=72). The organic fertilizers and minerals were distributed and incorporated in the plots 5 and 3 d before seedling transplant, respectively.

The lettuce plants were irrigated daily (drippers), with a flow rate of 1.8 L h⁻¹ spaced every 0.5 m, for approximately 40 min, maintaining the soil close to field capacity. Infestant plants (weeds) were manually controlled.

The harvest occurred 67 DAS and 42 days after transplant (DAT), when the plants presented commercial standards without evidence of flowering and with the maximum vegetative development. The plants were cut just below the basal leaves, close to the soil level, and brought to the laboratory to conduct the evaluations.

After the lettuce harvesting, the number of leaves (NL) was quantified, the plant height (PH) was measured with a graded ruler and the stem diameter (SD) were evaluated with caliper; the shoot fresh mass (SFM), shoot dry mass (SDM) and yield (P) were recorded using a digital scale with a maximum capacity of 20 kg. The harvested plants were dried at 65 °C with a forced air circulation oven for 72 h to determine the dry mass (SDM).

Four days after harvest, soil samples were collected in each plot in the 0-0.2 m soil layer for chemical analysis and determination of the residual effect of the fertilizers. The soil water pH, phosphorus (P) by Mehlich-1, potassium (K⁺), calcium (Ca²⁺), magnesium (Mg²⁺), potential acidity (H + Al), soil organic matter (SOM), sum of bases (Ca+Mg+K+Na) (SB), effective cation exchange capacity (CEC) ($t = SB + Al^{3+}$), CEC at pH 7 ($T = SB + (H+Al)$), and base saturation ($V = 100 SB/T$) were recorded.

The results were submitted to analysis of variance using the F test for significance. When the results presented significant differences ($P<0.05$), the data were submitted to analysis of regression for the quantitative factors (doses) and Tukey's test to the averages of qualitative factors (sources), both at 5% probability, using the AGROESTAT statistical software.

RESULTS AND DISCUSSION

The lettuce morphological parameters when using the CaM and ChM fertilizers were significantly higher ($P<0.05$) than when mineral fertilizer was applied (urea). For the doses, 150 and 0% were significantly higher and lower than the other doses for all parameters, respectively, but there was no interaction between the sources and doses (Tab. 1).

The use of CaM and ChM improved the soil chemical attributes after soil incorporation and increased all agronomic characteristics of the green-leaf lettuce. These results were due to the low natural fertility of Oxisols in the Cerrado biome. These soils generally present an accelerated rate of plant residue decomposition, low levels of organic matter, Ca, Mg, P and, consequently, a low cationic exchange capacity; thus, the use of organic fertilizers can improve the attributes of such soils.

Cunha *et al.* (2012) and Oliveira *et al.* (2014) showed that the application of organic compounds improves soil aeration and water absorption, as well as the chemical, physical and biological soil attributes, generating a balance in the availability of nutrients to plants as a function of useful microorganisms, macro and micronutrients that are available, natural antibiotics and growth substances, such as the humic fractions of organic matter.

The organic fertilization not only boosted productivity but also produced plants with a better nutritional

Table 1. Agronomic evaluation of green-leaf lettuce under different fertilizers and doses.

| Fertilizer | NL | PH | SD | SFM | SDM | Yield |
|--------------------------|--------------------|--------------------|--------------------|--------------------|--------------------|---------------------|
| | | cm | | g/plant | | Mg ha ⁻¹ |
| Fertilizers (F) | | | | | | |
| Urea | 16.4 b | 13.9 b | 1.1 b | 78.5 b | 3.4 b | 12.6 b |
| ChM | 22.0 a | 16.8 a | 1.5 a | 159.8 a | 9.4 a | 25.6 a |
| CaM | 23.2 a | 17.5 a | 1.5 a | 172.2 a | 9.8 a | 27.5 a |
| F-test | 65.87** | 18.45** | 28.69** | 39.09** | 34.89** | 39.09** |
| Doses (D) | | | | | | |
| 0 | 16.2 c | 12.8 c | 1.0 c | 62.7 d | 3.5b | 10.0 d |
| 25 | 19.8 b | 15.1 bc | 1.3 b | 113.5 c | 6.8 ab | 18.1 c |
| 50 | 21.0 ab | 16.1 ab | 1.4 b | 134.2 bc | 7.8 a | 21.5 bc |
| 100 | 22.0 ab | 17.1 ab | 1.5 a | 164.7 b | 8.7 a | 26.3 b |
| 150 | 23.0 a | 18.5 a | 1.5 a | 185.7 a | 9.3 a | 29.7 a |
| 200 | 21.6 ab | 17.0 ab | 1.4 b | 160.3 b | 9.3 a | 25.6 b |
| F-test | 13.53** | 9.71** | 10.93** | 14.75** | 6.57** | 14.75* |
| Interaction F × D | | | | | | |
| F-test | 1.16 ^{ns} | 0.69 ^{ns} | 0.86 ^{ns} | 0.96 ^{ns} | 0.92 ^{ns} | 0.96 ^{ns} |
| CV (%) | 10.69 | 13.68 | 14.24 | 29.14 | 39.24 | 29.13 |

^{ns} = non significant; ** = significant at 5%, by the Tukey test ($P < 0.05$).

ChM = chicken manure; CaM = cattle manure; NL = number of leaves; PH = plant height; SD = stem diameter; SFM = shoot fresh mass; SDM = shoot dry mass.

quality (arising from the improvement of soil quality) than the plants grown exclusively with mineral fertilizers (Silva *et al.*, 2011). Oliveira *et al.* (2014) emphasized that leafy vegetables respond well to organic fertilization and that the constant use of mineral fertilizers causes reductions in a soil's biological activity, which can affect the productive performance of crop cultures. Vaz *et al.* (2019) emphasized in their study that the commercial productivity of 14.5 Mg ha⁻¹ was observed at 157.4 kg of formulated 05-25-15 (NPK) and that doses above 200 kg ha⁻¹ reduced the number of total leaves and productivity.

The polynomial regression analysis demonstrated that the best fit to the averages of the analyzed variables was the quadratic model for NL, PH, SD, SFM, SDM and yield; the maximum values were 23.9, 17.4 and 1.6 cm, 182.4 and 11 g/plant and 29.5 Mg ha⁻¹, which corresponded to the doses 229.5, 181.5, 195, 213, 274.5 and 216 kg ha⁻¹ of N, which were equivalent to 153, 121, 130, 142, 183 and 144% of the recommended dose, respectively (Fig. 2).

According to Filgueira (2013), increases in the NL and PH favor vegetative development and expand

the photosynthetically active area of plants, raising the productive potential. This response was seen in the present study since, in the plots fertilized with CaM, the NL and PH increased by 43.7 and 25.9%, which caused an increase of 36.6% in the SD, 119.4% in the SFM, 188.23% in SDM and 118.25% in the lettuce productivity. In the plots fertilized with ChM, the values did not differ from the plots with CaM ($P > 0.05$); the NL and PH increased by 37.5 and 20.9%, which caused an increase of 36.6% in SD, 103.6% in SFM, 176.5% in SDM and 103.2% in the productivity when compared to the plots with mineral fertilization.

The study of the production of lettuce (Vanda cultivar) grown under protected environments and in an open field, with organic and mineral fertilization, using doses of 0, 1 and 2 times the recommendation for organic compost (3.6 kg m⁻² of NPK), mineral fertilizer [0.02 kg m⁻² of N, via urea, 0.08 kg m⁻² of P (simple superphosphate), and 0.008 kg m⁻² K (KCl)], indicated that the open environment had the highest averages with the highest dose of organic fertilization for PH (15.6 cm), the recommended dose of mineral fertilization for NL (8.6) and SD (1.13 cm) and a greater

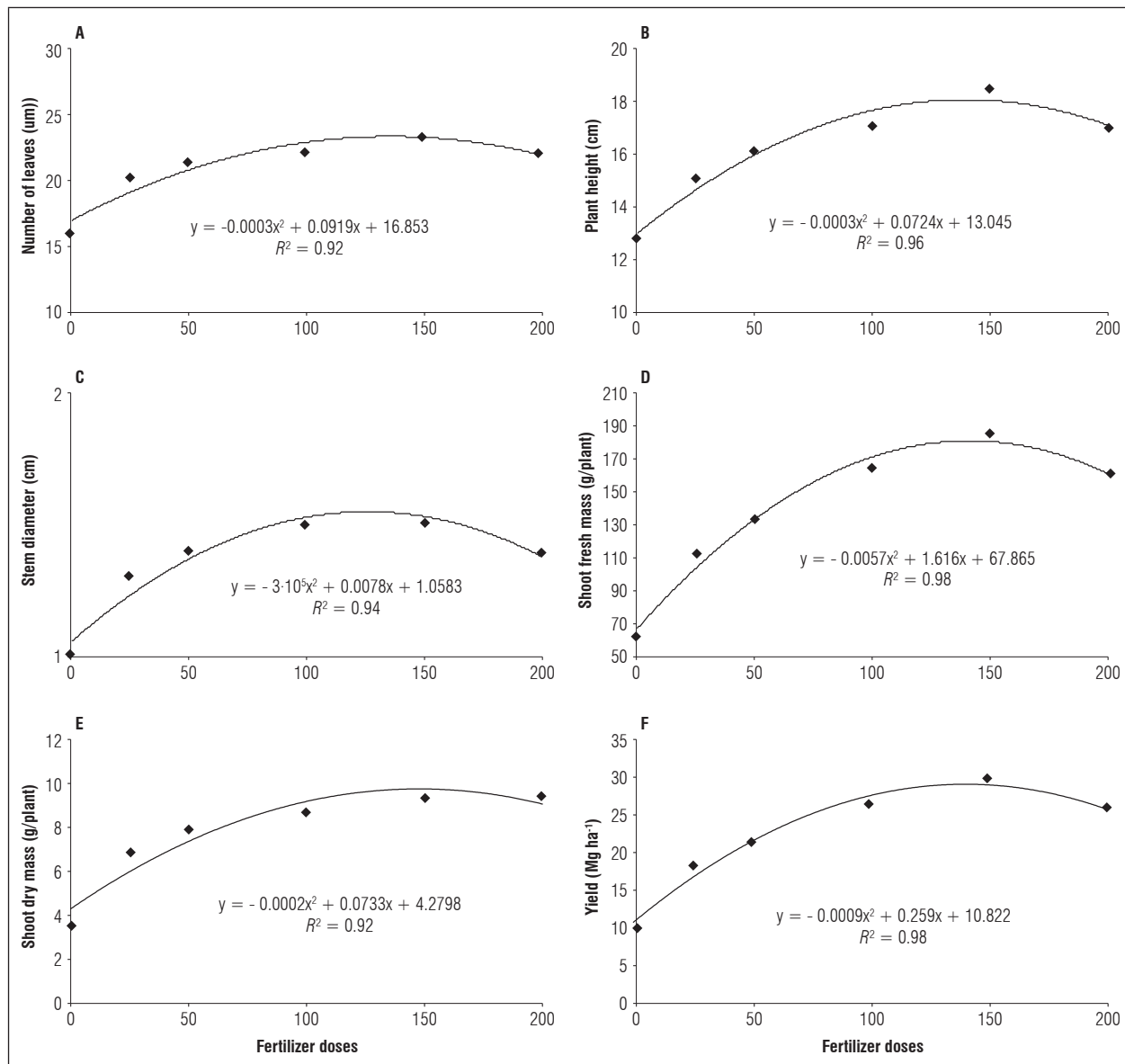


Figure 2. Effect of doses in the lettuce for number of leaves (A), plant height (B), stem diameter (C), shoot fresh mass (D), shoot dry mass (E), and yield (F), corresponding to the doses of 229.5 (153%), 181.5 (121%), 195.0 (130%), 213.0 (142%), 274.5 (183%) and 216.0 (144%) kg ha⁻¹ of N.

dose of mineral fertilization for SFM (96.8 g/plant) and productivity (36.0 Mg ha⁻¹) (Cavalheiro *et al.*, 2015). These values were lower than those found in the present study for NL (23.9), PH (17.4 cm), SD (1.6 cm), SFM (182.4 g/plant), and SDM (11.0 g/plant), except productivity (29.5 Mg ha⁻¹) (Tab. 2).

However, the greater organic fertilizer doses, which resulted in the greatest SFM, SDM and productivity, were 213 (142%), 274.5 (183%) and 216 (144%) kg

ha⁻¹ of N, respectively; however, the technical and economic feasibility of such application must be evaluated for each situation (Tab. 2).

The evaluation of the mineral fertilization, ChM, CaM, earthworm humus and organic compost in the production of lettuce (Vera cultivar) indicated a higher production when using ChM (Abreu *et al.*, 2010), presenting a SFM and SDM of 542.3 g, significantly higher when compared to the 91.1 g obtained with

Table 2. Regressions of the effects of fertilizer doses on the plant variables.

| Variable | Equation | R ² | Value reached | N doses | |
|----------|--|----------------|-----------------------------|---------------------|-----|
| | | | | kg ha ⁻¹ | % |
| NL | $y = -0.0003x^2 + 0.0919x + 16.853^{**}$ | 0.92 | 23.9 | 229.5 | 153 |
| PH | $y = -0.0003x^2 + 0.0724x + 13.045^{**}$ | 0.96 | 17.4 (cm) | 181.5 | 121 |
| SD | $y = -3E-05x^2 + 0.0078x + 1.0583^{**}$ | 0.94 | 1.6 (cm) | 195.0 | 130 |
| SFM | $y = -0.0057x^2 + 1.616x + 67.865^{**}$ | 0.98 | 182.4 (g/plant) | 213.0 | 142 |
| SDM | $y = -0.0002x^2 + 0.0733x + 4.2798^*$ | 0.92 | 11.0 (g/plant) | 274.5 | 183 |
| Yield | $y = -0.0009x^2 + 0.259x + 10.822^{**}$ | 0.98 | 29.5 (Mg ha ⁻¹) | 216.0 | 144 |

* = significant at 1% and ** = significant at 5%, by the Tukey test ($P < 0.05$). NL = number of leaves; PH = plant height; SD = stem diameter; SFM = shoot fresh mass; SDM = shoot dry mass.

CaM and the 233.1 g obtained with mineral fertilization. Peixoto Filho *et al.* (2013) assessed the productivity of green-leaf lettuce (Cacheada cultivar) with doses of chicken, cattle and ovine manure in successive cultivations and observed that the ChM provided the best indices for the evaluated parameters: NL (15), SFM (141.4 g), SDM (5.5 g) and P (26.7 Mg ha⁻¹).

For the residual effect on soil chemical attributes for the type of fertilizer used, the CaM showed the highest levels of magnesium (Mg) (1.7 cmol_c dm⁻³) and

organic matter (21 g kg⁻¹). Significant interactions between the fertilizers and doses for soil water pH, P and K were detected (Tab. 3; Fig. 3). In general, it was observed that the ChM resulted in a linear increase in soil pH, P and K, which ranged from 6.5 to 6.8, 19.9 to 86.8 mg dm⁻³ and from 0.2 to 0.5 cmol_c dm⁻³, respectively; 5, 335 and 104% higher than the control (no fertilizer). The urea fertilizer linearly increased the content of K by 64%, which ranged from 0.4 to 0.6 cmol_c dm⁻³ and linearly decreased the pH value by 7%, which ranged from 6.6 to 6.2.

Table 3. Chemical attributes of Oxisol cultivated with green-leaf lettuce under different fertilizers and doses.

| Fertilizer | Soil chemical attributes | | | | | | |
|-------------------|--------------------------|---------------------|------------------------------------|--------------------|--------------------|--------------------|--------------------|
| | pH | P | K | Ca | Mg | H+Al | OM |
| | CaCl ₂ | mg dm ⁻³ | cmol _c dm ⁻³ | | | | g kg ⁻¹ |
| | Fertilizers (F) | | | | | | |
| Urea | 6.4 b | 24.1 c | 0.5 a | 2.6 | 1.3 b | 1.9 | 18 b |
| ChM | 6.7 a | 49.2 a | 0.3 b | 2.9 | 1.5 ab | 1.7 | 19 b |
| CaM | 6.6 a | 37.9 b | 0.3 b | 2.8 | 1.7 a | 1.9 | 21 a |
| F-test | 3.51* | 16.10** | 35.98** | 2.20 ^{ns} | 5.46** | 3.76 ^{ns} | 8.37** |
| Doses (D) | | | | | | | |
| 0 | 6.6 | 19.6 d | 0.3 c | 2.4 | 1.3 | 2.0 | 18 |
| 25 | 6.5 | 28.2 cd | 0.4 b | 2.7 | 1.5 | 1.8 | 20 |
| 50 | 6.7 | 33.1 c | 0.3 c | 2.7 | 1.5 | 1.8 | 19 |
| 100 | 6.5 | 40.3 b | 0.4 b | 2.9 | 1.5 | 1.9 | 20 |
| 150 | 6.6 | 52.0 a | 0.4 b | 3.0 | 1.5 | 1.9 | 20 |
| 200 | 6.5 | 49.1 a | 0.5 a | 3.0 | 1.6 | 1.8 | 19 |
| F-test | 0.62 ^{ns} | 7.92** | 8.73** | 1.92 ^{ns} | 0.81 ^{ns} | 1.25 ^{ns} | 1.84 ^{ns} |
| Interaction F x D | | | | | | | |
| F-test | 2.33* | 4.21** | 4.87** | 1.34 ^{ns} | 0.91 ^{ns} | 1.88 ^{ns} | 1.37 ^{ns} |
| CV (%) | 4.35 | 41.46 | 20.80 | 20.84 | 22.87 | 15.25 | 10.28 |

^{ns} = non significant; * = significant at 1% and ** = significant at 5%, by the Tukey test ($P < 0.05$). ChM = chicken manure; CaM = cattle manure.

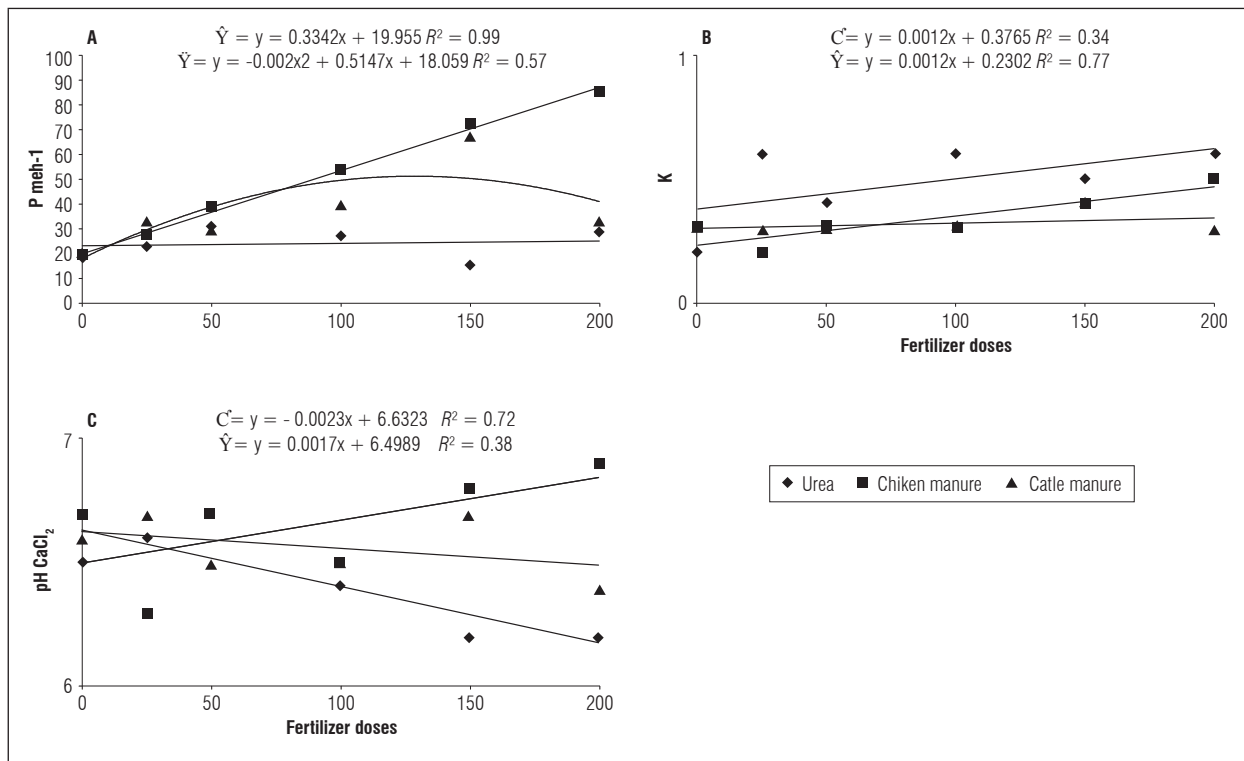


Figure 3. Regressions of the effect of doses of urea, chicken and cattle manure fertilizers on soil chemical attributes.

The increase in P availability, verified with the fertilization with ChM and CaM, was due to the presence of this nutrient in the manure composition, to the soil pH and to the rise in the soil organic matter content. The soil pH near neutrality provided conditions for P availability; in acidic conditions, there is a reaction of H_2PO_4^- with the ionic forms of iron (Fe) and aluminum (Al), forming compounds with low solubility; also, the presence of organic matter blocks the adsorption sites on Fe and Al oxides in the soil, decreasing the adsorption capacity of H_2PO_4^- (Novais and Smyth, 1999).

The study of polynomial regression indicated that the soil pH in the soil fertilized with ChM and urea presented a linear adjustment, reaching values of 6.8 and 6.2, respectively, with the 200% dose. The soil P when fertilized with ChM and CaM presented a linear and quadratic adjustment, respectively, reaching values of 86.8 mg dm^{-3} with the 200% dose and 51.2 mg dm^{-3} with the 129% dose. The soil K in the areas fertilized with urea and ChM presented a linear adjustment, reaching values of 0.6 and 0.5 cmolc dm^{-3} with the 200% fertilized doses, respectively (Tab. 4).

Table 4. Regression equations of the effect of doses of fertilizers on soil chemical attributes.

| Soil attribute | Equation | R^2 | Fertilizer | Value reached | Dose | Variation |
|------------------------------|--------------------------------------|-------|------------|---------------|------|-----------|
| pH | $y = -0.0023x + 6.6323^{**}$ | 0.72 | Urea | 6.2 | 200 | -7 |
| | $y = 0.0017x + 6.4989^*$ | 0.38 | ChM | 6.8 | 200 | 5 |
| P (mg dm^{-3}) | $y = 0.3342x + 19.955^{**}$ | 0.99 | ChM | 86.8 | 200 | 335 |
| | $y = -0.002x^2 + 0.5147x + 18.059^*$ | 0.57 | CaM | 51.2 | 129 | 183 |
| K (mg dm^{-3}) | $y = 0.0012x + 0.3765^{**}$ | 0.34 | UR | 0.6 | 200 | 64 |
| | $y = 0.0012x + 0.2302^{**}$ | 0.77 | ChM | 0.5 | 200 | 104 |

* = significant at 1%, and ** = significant at 5%, by the Tukey test ($P < 0.05$). ChM = chicken manure; CaM = cattle manure; pH = soil water pH; P = phosphorus (Mehlich-1); K = potassium.

Pimentel *et al.* (2009) conducted two experiments on lettuce and carrot [the first experiment was fertilized with organic compound (70% of Napier grass, 10% of remnants of cultures, 20% of cattle manure) at 0, 4.2, 8.4 and 16.8 kg/parcel (dry basis); the second experiment was fertilized with 1/3 of the previous organic compound plus various grasses at 0, 3.4, 6.9 and 13.7 kg parcel⁻¹ (dry basis)], and observed that the levels of P and K increased regardless of the organic compound used. The authors reported that the soil pH in both experiments was close to neutrality (6.7 and 6.6), as well as in the present study.

According to Mantovani *et al.* (2005), green-leaf lettuce (cultivar Verônica) fertilized with 0, 30, 60, 90 and 120 Mg ha⁻¹ of urban waste compost presented linear increases in soil pH (CaCl₂), soil organic matter, P, K, Ca and Mg, with increases of 19, 28, 81, 27, 178 and 100%, respectively, as compared to the control treatment (highest dose of organic fertilizer). This authors also reported that this effect on soil pH can be attributed to the presence of soluble organic anions (R-COO⁻ and R-O⁻) in organic waste, which can adsorb H⁺ from the soil solution with exchange reactions, especially with Ca²⁺ ions.

The correlation of the soil chemical characteristics and biomass production of the lettuce fertilized with organic compounds indicated that the addition of organic compounds increased the production of lettuce dry mass and the content of soil organic matter in the soil (Oliveira *et al.*, 2014). These authors also reported that the rise of soil organic matter provided greater P, K and Ca availability, in addition to a reduced soil potential acidity, favoring plant development and increasing productivity, similar to what was observed in the present study.

After harvest, there was still a residual of 49.2 mg dm⁻³ of P in the plots fertilized with ChM (Tab. 5), indicating that there was a greater availability of this nutrient in an Oxisol (high P adsorption), which is a common soil in the Cerrado.

The microbiological quality and productivity of lettuce (Vera cultivar) under mineral and diverse organic fertilization treatments (control without fertilization, chemical fertilization, chicken manure, cattle manure, earthworm humus, organic compost) indicated that the fertilization with chicken manure provided the highest soil pH (7.1), K (0.46 cmol_c dm⁻³),

Table 5. Soil pH, phosphorus and potassium levels according to fertilizer.

| Fertilizer | Doses | | | | | | Average |
|------------|---|----------|----------|-----------|---------|---------|---------|
| | 0 | 25 | 50 | 100 | 150 | 200 | |
| | pH | | | | | | |
| Urea | 6.5 aA | 6.6 aA | 6.7 aA | 6.4 aA | 6.2 bA | 6.2 bA | 6.4 b |
| ChM | 6.7 aAB | 6.3 aB | 6.7 aAB | 6.5 aAB | 6.8 aAB | 6.9 aA | 6.7 a |
| CaM | 6.6 aA | 6.7 aA | 6.5 aA | 6.5 aA | 6.7 abA | 6.4 abA | 6.6 ab |
| Average | 6.6 A | 6.5 A | 6.7 A | 6.5 A | 6.6 A | 6.5 A | -- |
| CV (%) | 4.35 | | | | | | |
| | P (mg dm ⁻³) | | | | | | |
| Urea | 19.2 aA | 23.8 aA | 30.3 aA | 26.5 bA | 15.3 bA | 29.3 bA | 24.1 c |
| ChM | 18.5 aC | 27.3 aBC | 38.7 aBC | 53.9 aAB | 72.3 aA | 84.5 aA | 49.2 a |
| CaM | 20.9 aB | 33.6 aB | 30.4 aB | 40.5 abAB | 68.4 aA | 33.5 bB | 37.9 b |
| Average | 19.6 D | 28.2 CD | 33.1 BCD | 40.3 ABC | 52.0 A | 49.1 AB | -- |
| CV (%) | 41.46 | | | | | | |
| | K (cmol _c dm ⁻³) | | | | | | |
| Urea | 0.2 aC | 0.6 aA | 0.4 aB | 0.6 aAB | 0.5 aAB | 0.6 aA | 0.5 a |
| ChM | 0.3 aBC | 0.2 bC | 0.3 aBC | 0.3 bABC | 0.4 aAB | 0.5 bA | 0.3 b |
| CaM | 0.3 aA | 0.3 bA | 0.3 aA | 0.3 bA | 0.4 aA | 0.3 cA | 0.3 b |
| Average | 0.3 c | 0.4 abc | 0.3 bc | 0.4 ab | 0.4 a | 0.5 a | -- |
| CV (%) | 20.80 | | | | | | |

Means followed by different letter indicate significant differences according to Tukey test ($P \leq 0.05$). ChM = chicken manure; CaM = cattle manure.

Ca ($6.8 \text{ cmol}_c \text{ dm}^{-3}$), Mg ($1.1 \text{ cmol}_c \text{ dm}^{-3}$), and CTC ($11.2 \text{ cmol}_c \text{ dm}^{-3}$), while the fertilization with cattle manure showed the highest values for soil organic matter (51.8 g kg^{-1}) and P (16 mg dm^{-3}), results that corroborate an improvement in soil chemical attributes when cultivated with organic fertilizers.

Mantovani *et al.* (2014) found that high doses of P resulted in an increased growth and production of green-leaf lettuce and observed that a dose of 350 mg dm^{-3} , equivalent to 800 kg ha^{-1} of P_2O_5 , was the most appropriate dose for clay soils (420 g kg^{-1} of clay). Abreu *et al.* (2010) demonstrated that plants from treatments with organic composts showed a high foliar P and K content, higher than those observed in a mineral fertilization treatment. The authors also pointed out that N and P are the elements that most commonly limit lettuce production as a result of low availability in the soil.

CONCLUSIONS

The fertilization with cattle manure and chicken manure was more efficient than the mineral fertilization for the production of green-leaf lettuce, mainly because of P residual effects in the soil.

The chicken manure provided a higher soil pH, phosphorus and potassium, and the cattle manure provided a higher magnesium, organic carbon and organic matter content.

The 144% dose of organic fertilization (wet basis), corresponding to 72 Mg ha^{-1} of cattle manure and 29 Mg ha^{-1} of chicken manure, resulted in the highest yield for green-leaf lettuce.

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BIBLIOGRAPHIC REFERENCES

- Abreu, I.M.O., A.M.R. Junqueira, J.R. Peixoto, and S.A. Oliveira. 2010. Qualidade microbiológica e produtividade de alface sob adubação química e orgânica. *Ciênc. Tecnol. Aliment.* 30(Suppl. 1), 108-118. Doi: 10.1590/S0101-20612010000500018
- Beck, H.E., N.E. Zimmermann, T.R. Mcvigar, N. Vergopolan, A. Berg, and E.F. Wood. 2018. Present and future Köppen–Geiger climate classification maps at 1-km resolution. *Sci. Data* 5, 180214. Doi: 10.1038/sdata.2018.214
- Carvalho, N.L. and V. Zabot. 2012. Nitrogênio: nutriente ou poluente? *Rev. Eletrônica Gest., Educ. Tecnol. Ambient.* 6(6), 960-974. Doi: 10.5902/223611704671
- Cavaleiro, D.B., E.S. Klosowski, N.P. Henkemeier, A.C. Gonçalves Junior, E.S. Vasconcelos, and E. Chibiaqui. 2015. Produção de alface (*Lactuca sativa* L.) cv. Vanda, cultivada sob diferentes ambientes e níveis de adubação mineral e orgânica. *Cult. Saber* 8(1), 109-124.
- Cunha, E.Q., L.F. Stone, E.P.B. Ferreira, A.D. Didonet e J.A.A. Moreira. 2012. Atributos físicos, químicos e biológicos de solo sob produção orgânica impactados por sistemas de cultivo. *Rev. Bras. Eng. Agríc. Ambient.* 16(1), 56-63. Doi: 10.1590/S1415-43662012000100008.
- Figueiredo, C.C., M.L.G. Ramos, C.M. McManus, and A.M. Menezes. 2012. Mineralização de esterco de ovinos e sua influência na produção de alface. *Hortic. Bras.* 30(1), 175-179. Doi: 10.1590/S0102-05362012000100029
- Filgueira, F.A.R. 2013. Novo manual de olericultura: agrotecnologia moderna na produção e comercialização de hortaliças. 3th ed. UFV, Viçosa, Brazil.
- Inmet, Instituto Nacional de Meteorologia Brazil. 2018. Gráficos climatológicos. In: <http://www.inmet.gov.br/portal/index.php?r=tempo/graficos>; consulted: August, 2019.
- Mantovani, J.R., M.E. Ferreira, M.C.P. Cruz, and J.C. Barbosa. 2005. Alterações nos atributos de fertilidade em solo adubado com composto de lixo urbano. *Rev. Bras. Ciênc. Solo* 29(5), 817-824. Doi: 10.1590/S0100-06832005000500017
- Mantovani, J.R., I.A.C. Oliveira, D.J. Marques, A.B. Silva, and P.R.C. Landgraf. 2014. Teores de fósforo no solo e produção de alface crespa em função de adubação fosfatada. *Semina: Ciênc. Agrár.* 35(Suppl 4), 2369-2380. Doi: 10.5433/1679-0359.2014v35n4Suplp2369
- Melo, L.C.A., C.A. Silva, and B.O. Dias. 2008. Caracterização da matriz orgânica de resíduos de origens diversificadas. *Rev. Bras. Ciênc. Solo* 32(1), 101-110. Doi: 10.1590/S0100-06832008000100010
- Mota, W.F., R.D. Pereira, G.S. Santos, and J.C.B. Vieira. 2012. Agronomic and economic viability of intercropping

- onion and lettuce. *Hortic. Bras.* 30(2), 349-354. Doi: 10.1590/S0102-05362012000200028
- Novais, R.F. and T.J. Smyth. 1999. Fósforo em solo e planta em condições tropicais. UFV, Viçosa, Brazil.
- Oliveira, L.B., A.M.A. Accioly, C.L.R. Santos, R.A. Flores, and F.S. Barbosa. 2014. Características químicas do solo e produção de biomassa de alface adubada com compostos orgânicos. *Rev. Bras. Eng. Agríc. Ambient.* 18(2), 157-164. Doi: 10.1590/S1415-43662014000200005
- Peixoto Filho, J.U., M.B.G.S. Freire, F.J. Freire, M.F.A. Miranda, L.G.M. Pessoa, and K.M. Kamimura. 2013. Produtividade de alface com doses de esterco de frango, bovino e ovino em cultivos sucessivos. *Rev. Bras. Eng. Agríc. Ambient.* 17(4), 419-424. Doi: 10.1590/S1415-43662013000400010
- Pereira, D.C., A. Wilsen Neto, and L.H.P. Nóbrega. 2013. Adubação orgânica e algumas aplicações agrícolas. *Varia Sci. Agrár.* 3(2), 159-174.
- Pimentel, M.S. H. De-Polli, and A.M.Q. Lana. 2009. Atributos químicos do solo utilizando composto orgânico em consórcio de alface-cenoura. *Pesqui. Agropecu. Trop.* 39(3), 225-232.
- Queiroz, A.A., V.B. Cruvinel, and K.M.E. Figueiredo. 2017. Produção de alface americana em função da fertilização com organomineral. *Encicl. Biosf.* 14(25), 1053-106. Doi: 10.18677/EnciBio_2017A84
- Ribeiro, A.C., P.T.G. Guimarães, and V.H. Alvarez V. (eds.). 1999. Recomendações para o uso de corretivos e fertilizantes em Minas Gerais. 5th ed. Comissão de Fertilidade do Solo do Estado de Minas Gerais, Viçosa, Brazil.
- Sala, F.C. and C.P. Costa. 2012. Retrospectiva e tendência da alfacultura brasileira. *Hortic. Bras.* 30(2), 187-194. Doi: 10.1590/S0102-05362012000200002
- Santos, H.G., P.K.T. Jacomine, L.H.C. Anjos, V.A. Oliveira, J.F. Lumbrellas, M.R. Coelho, J.A. Almeida, T.J.F. Cunha, and J.B. Oliveira. 2018. Sistema brasileiro de classificação de solos. 5th ed. Embrapa, Brasília, Brazil.
- Silva, E.M.N.C.P., R.L.F. Ferreira, S.E. Araújo Neto, L.B. Tavella, and A.J.S. Solino. 2011. Qualidade de alface crespa cultivada em sistema orgânico, convencional e hidropônico. *Hortic. Bras.* 29(2), 242-245. Doi: 10.1590/S0102-05362011000200019
- Souza, J.L. 2007. Cultivo orgânico de hortaliças: Sistema de produção. CPT, Viçosa, Brazil.
- Tedesco, M.J., P.A. Selbach, C. Gianello, and F.A.O. Camargo. 2008. Resíduos orgânicos no solo e os impactos no ambiente. In: Santos, G.A., L.S. Silva, L.P. Canellas, and F.O. Camargo (eds.). 2008. Fundamentos da matéria orgânica do solo: ecossistemas tropicais e subtropicais. 2nd ed. Metrópole, Porto Alegre, Brazil.
- Vaz, J.C., A.T. Tavares, F.M. Haesbaert, I.D.P. Reyes, P.H.L. Rosa, T.A. Ferreira, and I.R. Nascimento. 2019. Adubação NPK como promotor de crescimento em alface. *Rev. Agri-Environ. Sci.* 5, e019003. Doi: 10.36725/agries.v5i0.1215
- Vergel, O.M, J.J. Martínez., and S.L. Zafra. 2016. Cultivo de cebolla (*Allium cepa* L.) en la provincia de Ocaña: factores asociados a la productividad y el rendimiento, *Rev. Colomb. Cienc. Hortic.* 10(2), 333-344. Doi: 10.17584/rcch.2016v10i2.5070