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Yield components of lettuce cultivars submitted to different phosphate sources

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ABSTRACT. There is little information available concerning the effects of different sources and levels of phosphorus in the soil on lettuce quality and production. To help determine an optimal strategy, we used complete randomized blocks, in a 2x3x5 factorial experimental design, with two commercial lettuce cultivars widely used in Brazil (Americana (iceberg lettuce) cv. Lucy Brown and Crespa (leafy lettuce) cv. Vanda) fertilized with one of three phosphate sources [MAP, Polyblen or Triple Super Phosphate (SPT)], at five concentrations (0, 250, 500, 750 or 1000 kg of P_2O_5 ha^{-1}), with three replicates planted on a farm in Mineiros, GO. The variables stem height, head diameter, number of commercial and non-commercial heads and commercial fresh weight, were analyzed at 40 days after planting. There was a triple interaction for these factors, when their averages were broken down to qualitative and quantitative effects. The variables were correlated, and affinities with the genotype x phosphate source interaction were found. Based on the yield data, the recommendations for Americana are 911, 680 or 457 kg P_2O_5 ha^{-1} from MAP, Polyblen, and SPT, respectively. For Crespa the recommendations are 580 or 611 kg P_2O_5 ha^{-1} from MAP and SPT, respectively.

Key words: *Lactuca sativa*; Phosphorus; Plant nutrition

INTRODUCTION

The leafy vegetables are vegetable species that have been gaining prominence due to the great demand as an option in meals. These vegetables are considered the most consumed in the world, presenting great diversity of color, texture, flavor, form of preparation and use; among which stand out the lettuce crop. In order to meet the demand of the consumer market in quantity, quality and regularity of vegetables, it is necessary to use cultivation systems with high productivity (Nascimento et al., 2017).

Lettuce (*Lactuca sativa*), belonging to the Asteraceae family, is a leafy vegetable that has great prominence in the world (Melo et al., 2017). It is characterized as being the main leafy vegetable consumed and commercialized in Brazil (Pacheco Silva et al., 2016); furthermore, lettuce cultivation is of great economic return per acre. It is, therefore, an agricultural activity very characteristic of much of Brazil, including the southwest region of Goiás, developed mainly by family farms (Ferreira et al., 2018).

Among the various lettuce groups, the types Americana (iceberg lettuce) and Crespa (leaf lettuce) present leaves with good visual aspects, ease of processing, good post-harvest conservation and resistance to transportation and handling. Usually, their preference is attributed to middle-upper-class consumers for the first type and poorer consumers, for the second, respectively. The cultivars Americana cv. Lucy Brown and Crespa cv. Vanda, currently dominate approximately 90% of the consumer market of Mineiros, GO and the surrounding region.

Lettuce is a highly fertilizer dependent crop and the application of correct doses based on soil element content is of fundamental importance both for the economic viability of the crop and for mitigating the negative impacts that this action causes to the environment (Cecílio Filho et al., 2018). Lettuce may be considered as very demanding in phosphorus, especially in the final phase of its cycle (Lana et al., 2004).

Phosphorus (P) is one of the nutrients that contribute most to the physiological mechanism of plants and is directly related to energy metabolism and membrane formation and cell wall. Some species, in particular, present high demand for P availability, such as lettuce. Its scarcity may provide rickety plant development, susceptibility to pest attack, low resistance to weather stresses, and brittle leaves with low shelf life (Taiz et al., 2017).

For Katayama (1993), P is important for a large number of compounds that are essential plant in various metabolic processes, in addition to stimulating root development. Its deficiency, in lettuce cropping, reduces the growth of the plant, causing poor formation and the old leaves become green-opaque in coloration, being able to present red-bronze or purple tonality, losing their commercial value.

The soils under Cerrado vegetation, mainly the latosols, present chemical limitations for the adequate growth of the plants, with emphasis on the low nutrient content and the high capacity of phosphate adsorption (Guimarães et al., 1993; Lana et al., 2004). The low efficiency of phosphate fertilization evidences the necessity of new fertilization methods regarding sources and times of application (Guimarães et al., 1993).

The application of phosphate fertilizers with adequate doses is a convenient strategy, since the composition, mainly leaves, provides a high response to the availability of this mineral. In Brazilian agriculture, the main phosphate sources are the Monoammonium Phosphate (MAP) and the Triple Superphosphate (SPT). Other sources

such as Polyplen, in the category of gradual release fertilizer, has been gaining ground among the local lettuce producers.

The development of research aiming to identify the best fertilizer doses for different cultivars, planting times and regions, still constitutes a necessary investment in Brazil (Melo et al., 2017). In the literature, there are few studies showing the behavior of sources and levels of phosphorus in the soil for the region of Southwest of Goiás. Thus, the objective of this work was to evaluate the behavior of cultivars of Crespa and Americana lettuce as a function of different phosphate sources applied via soil.

MATERIAL AND METHODS

The study was conducted in the Horta dos Coqueiros private property, in the municipality of Mineiros-GO, located between the geographic coordinates of 17°34'10" South latitude and 52°33'04" West longitude, with an average altitude of 760 m. The experimental area is classified as Aw climate (hot and dry) (Köppen and Geiger, 1936). The soil of the experimental area was classified Typic Quartzipisamment, with light texture, smoothly waved topography and good drainage (Embrapa, 2013).

It was carried out, prior to the installation of the experiment, the chemical analyzes and soil granulometry of the 0-20 cm layer, revealing the following results: pH in $CaCl_2$ 0.01 $mol.L^{-1}$ 6.1; phosphorus in Mehlich1 172 $mg.dm^{-3}$; potassium 0.12, calcium 7.5, magnesium 0.9, aluminum 0, hydrogen 16, in c $mol_c.dm^{-3}$; clay 14, silt 5 and sand 81, in %. The analyzes were performed at the UNIFIMES Soil Chemistry and Fertility Laboratory, according to the methodology of (Embrapa, 2009).

The experimental design was a randomized complete block design in a 2x3x5 factorial scheme, totaling 30 treatments, corresponding to 2 lettuce cultivars [Americana (A) cv. Lucy Brown and Crespa (C) cv. Vanda] submitted to the 3 phosphate sources [Monoammonium Phosphate (MAP), Polyblen and Triple Super Phosphate (SPT)], being these submitted to 5 concentrations [0, 250, 500, 750, and 1000 kg of P_2O_5 ha^{-1}], in 3 replicates. The transplant of the seedlings to the field occurred on May 4, 2018.

Regarding the soil preparation, it was carried out in the conventional system with plowing and harrowing. Each plot, in seedbed, was scaled to 1.20 m length by 1.20 m wide and 0.10 m high. Fertilizers at their respective doses were incorporated into the 0-5 cm layer on the day of transplantation. The use of soil cover with agricultural *mulching* was carried out. The seedlings were grown in polystyrene trays filled with commercial Plantmax® substrate (B&L Joinville - SC). The seedlings were transplanted 20 days after sowing in the trays. The plots were composed of 16 plants each, spaced 0.3x0.3 m. During the experiment, pest, disease and weed control was carried out whenever necessary, respecting good practices and integrated management (Ferreira et al., 2019). The irrigation system used was Santeno (tape) in the between the beds (Ferreira et al., 2019).

The variables were analyzed 40 days after planting on June 15, 2018, determing: plant height (PH) in cm; stem diameter (SD) in cm; number of commercial (CLN) sheets, non-commercial (NCLN) and total (TLN) in unid and fresh weight of head (FWH) in g per plant, were determined according to the methodology of Benincasa (2004). The data obtained were submitted to the assumptions of the statistical model, verifying the normality and homogeneity of the residual variances, as well as the additivity of the model. Afterwards, the variance analysis was carried out to identify the interaction between lettuce

(A) x phosphate sources (F) x phosphorus doses (D) and, to verify significant interaction, these were opened to the simple effects through grouping Tukey's test at the 5% probability. Subsequently, the variables were submitted to a linear correlation with the purpose of understanding the association tendency, and their significance was based on a probability of 5% by the t-test. In addition, the biplot canonical variable method was applied to visualize the general variability of the experiment and the multivariate trends. The analyses were performed using the Rbio and R interface (Bhering, 2017).

RESULTS

The triple interaction factors (F x H x D), and simple as lettuce (A) and dose (D) were significant for all variables ($P < 0.01$). The double interactions (A x F and A x D) did not influence the means of TLN and CLN. The phosphorus factor was significant for SD, NCLN, FWH ($P < 0.0\ 1$) and TLN ($P < 0.0\ 5$) (Table 1). These findings corroborate with Lana et al. (2004), Nascimento et al. (2017), Melo et al. (2017), Rezende et al. (2017), Porto et al. (2014) and Ferreira et al. (2018). The behavior of lettuce crops may vary depending on climatic conditions, genetics chosen, fertilizer level and sources, as well as soil type as reported by Smith and Scaife (1973) when concluding in their work that the necessary amounts of phosphorus for the maximum growth of this Asteraceae ranged from 120 ppm in sandy soil to 300 ppm in clayey where such differences in requirement were related to soil phosphorus adsorption.

Table 1. Summary of variance analysis (calculated F and CV (%)) for lettuce plant height (PH), stem diameter (SD), commercial leaf number (CLN), non-commercial leaf number (NCLN), total leaf number (TLN) and fresh weight of head (FWH). Mineiros - GO, UNIFIMES, Brazil, 2020.

Factors	DF	PH ALT	SD DIC	CLN FCO	NCLN FNC	TLN FTO	FWH PFC
A x F x D	8	4.6 **	8.7 **	5.2 **	2.8 **	9.1 **	17.6 **
A x F	2	3.1 *	10.2 **	0.3 ns	6.1 **	1.6 ns	104.8 **
A x D	4	7.8 **	8.5 **	1.0 ns	1.3 **	1.0 ns	4.2 **
Lettuce (A)	1	391.2 **	313.4 **	16.7 **	47.3 **	55.8 **	122.1 **
Phosphorus (F)	3	0.4 ns	18.9 **	2.6 ns	1.2 **	3.1 *	30.9 **
Dose (D)	4	9.2 **	64.3 **	11.7 **	22.1 **	14.7 **	134.6 **
CV (%)		10.56	2.33	4,94	11.29	4.90	3.57

** significant at 1% probability by F test; * significant at 5% probability by F test; ns not significant at 5% probability by the F test.

The alignment of the cultivars inside the phosphate sources showed the cv. Crespa with the highest averages in PH, SD, CLN and TLN characteristics. Influences of the alignment of the phosphate sources within the cultivars were observed in the reduction of SD and TLN in cv. Americana by SPT and Polyblen sources, respectively, in addition to FWH by Polyblen in cv. Crespa and low CLN by cv. Americana in MAP (Table 2). The different behaviors verified are explained by Fageria et al. (1999), when reporting that phosphorus sources react differently as a function of soil characteristics, such as soil phosphorus level, phosphorus adsorption capacity, soil buffering capacity, acidity and exchangeable aluminum content.

Table 2. Analysis of lettuce cultivars fertilized with different phosphate sources and effects on plant height (PH), stem diameter (SD), commercial leaf number (CLN), non-commercial leaf number (NCLN), total leaf number (TLN) and fresh weight of head (FWH). Mineiros-GO, UNIFIMES, Brazil, 2020.

Cultivars	Phosphate sources PH (cm)			Phosphate sources SD (cm)			Phosphate sources FCO (unit plant $^{-1}$)		
	MAP	Polyblen	SPT	MAP	Polyblen	SPT	MAP	Polyblen	SPT
Americana	3.72 bA	3.60 bA	3.31 bA	28.10 bA	28.47 bA	26.70 bB	19.51 bAB	19.07 bb	20,12bA
Crespa	5.44 aA	5.56 aA	5.65 aA	30.39 a A	30.34 to A	30.11 a A	20.92 aA	21.17 aA	21.32 aA
CV (%)	10.56			2.33			4.90		
	NCLN (unit plant $^{-1}$)			TLN (unit plant $^{-1}$)			FWH (g $^{-1}$ head)		
Americana	3,46aB	3.94 aA	3.68 aAB	22.97 b A	23.02 bA	23.81 aA	424 b C	514aA	461 aB
Crespa	3,20aA	3.00 bA	3.21 bA	24.12 aA	24.18 aA	24.53 aA	437 to A	411 bb	439 bA
CV (%)	11.29			4.94			3.57		

Means followed by the same letter in uppercase and the column line does not differ by Tukey's test at 5% probability.

For the results of PH for the cv. Crespa, the doses of MAP and SPT presented distinct behavior, being observed linear and quadratic adjustment, respectively. The maximum PH of cv. Crespa was 5.78 cm at a dose of 476.25 kg.ha^{-1} of MAP, and with SPT, this variable was raised at 16% in the maximum dose of the fertilizer (Figure 1α). These results corroborate with Mota et al (2003) who found 6.7 cm using SPT e Sousa et al (2018), 6.5 cm. According to Sala and Costa (2012), the characteristics of lettuce plants such as PH and SD are important because they provide information for the packaging of plants for transportation in plastic or wooden boxes, in addition to interfering with productivity.

For the results of SD, it was observed that cv. Americana in the dose of 490 kg P_2O_5 ha^{-1} of MAP raised the SD to 30 cm. Analogous behavior to that observed with the fertilizer Polyblen (Figure 1β). For cv. Crespa (Figure 3γ), the concentration of Polyblen normalized at the dose of 563 kg of P_2O_5 h^{-1}, with SD obtaining 32 cm. By using the SPT was possible to obtain an increase of 11% in SD, less than was found by Lana et al. (2004), using SPT, where they obtained SD of 21,37 cm, by Nascimento et al. (2017) with 26.78 cm and 26 cm found by Melo et al. (2017). The SD characteristic is an important characteristic for the lettuce type Americana, considering the consumer preference for larger heads in the product acquisition (Queiroz et al., 2017).

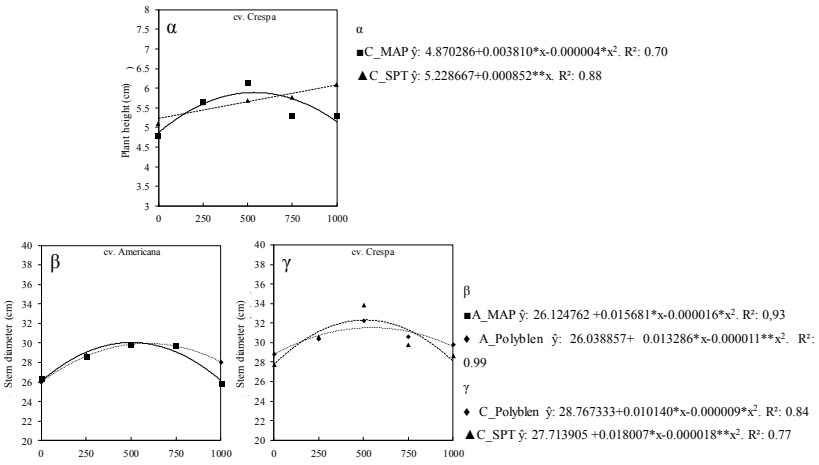

Figure 1. Plant height PH (α); stem diameter SD lettuce (β) and Crespa - C (γ), submitted to phosphate sources MAP, Polyblen and SPT, depending on the concentration of phosphorus as P_2O_5. UNIFIMES, Mineiros - GO, Brazil, 2020.

In relation to NCLN, the cv. American decreased linearly with the MAP and Polyblen sources (Figure 2α). The same was observed in cv. Crespa, in all phosphate sources (Figure 2b). The NCLN presented values below five leaves for both cv. Americana as for cv. Crespa (Figure 2α and 2β). Values equal or greater five non-commercial leaves reduces the yield of the lettuce crop, including its appearance in the gondolas. As occurred in Brzezinski et al. (2017) when verifying 12 NCLN and only 15 CLN, being decisive for the low yield and return of the culture.

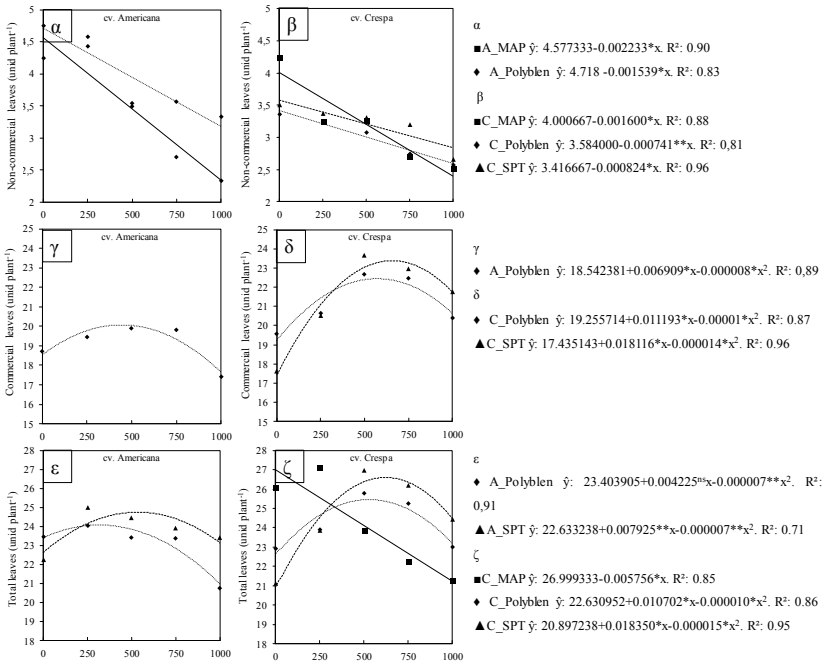

Figure 2. Number of non-commercial leaves (NCLN) of Americana lettuce - A (α) and Crespa - C (β); commercial leaves (CLN) of Americana lettuce - A (γ) and Crespa - C (δ); and total leaves (TLN) of Americana lettuce - A (ε) and Crespa - C (ζ), submitted to the phosphate sources MAP, Polyblen and SPT, under phosphorus concentrations in P2O5. UNIFIMES, Mineiros - GO, Brazil, 2020.

For CLN, in cv. Americana, the Polyblen doses present a quadratic adjust, if normalized in the dose of 432 kg of P_2O_5 ha^{-1}, generating an estimate of 20 unites (Figure 2γ). The CLN of cv. Crespa, when under Polyblen doses, normalized in the dose of 560 kg of P_2O_5 ha^{-1}, generating an average number of 22 units. The SPT propitiated an increase of 4% in CLN, although being necessary the addition of 647 kg of P_2O_5 ha^{-1} (Figure 2δ). Similar results were reported by Rezende et al. (2017) and Nascimento et al. (2017), with averages of 22 and 20 leaves per plant, respectively. This character is directly related to yield, since, besides the number, the expansion of leaf area potentiate the crop fresh matter.

In relation to TLN, in cv. Americana, the Polyblen doses presented quadratic effect (24 leaves $unit^{-1}$ $head^{-1}$) obtained in the dose of 320 kg of P_2O_5 ha^{-1}. Similar behavior was observed in the SPT source, being possible to increase by 4% the TLN, although, it was necessary to increase the dose of P_2O_5 ha^{-1} by 43%. For the cv. Crespa, the Polyblen doses were optimized under 536 kg P_2O_5 ha^{-1}, producing 25 leaves. The same curve behavior was

registered in the SPT doses, being observed that the dose of 612 kg P_2O_5 ha^{-1} implicates an increase of 7% in TLN (Figure 2ε). These results allow the increase in yield, with a financial return to the farmer, by indicating the best management condition for each lettuce cultivar, although, the relation of TLN and NCLN must be as high as possible.

The FWH in the cv. Americana, when using 911 kg of P_2O_5 ha^{-1} of MAP, elevated the same to 469 $g.plant^{-1}$. In the dose of 680 kg of P_2O_5 ha^{-1} of Polyblen, there was an increase of 19% in FWH, although when using 457 kg of P_2O_5 ha^{-1}, it was possible to observe a PFC of 496 g $plant^{-1}$ (Figure 3α). For the cv. Crespa, the MAP doses under 580 kg of P_2O_5 ha^{-1} generated an upsurge of 0.6%. When using 611 kg of P_2O_5 ha^{-1} of SPT, it allowed obtaining a PFC of 481 $g.plant^{-1}$ (Figure 3β). Increases were also reported by Porto et al. (2014), Pacheco Silva et al. (2016) and Lana et al. (2004), using phosphate sources. In addition, in the Southwest of Goias, Queiroz et al. (2017) concluded that the dose of 1600 kg ha^{-1} of organomineral (presence of P) was the one with better results for all parameters analyzed in the lettuce crop. For Hoque et al. (2010) applying moderate doses of N and P increased lettuce yield and improved postharvest quality.

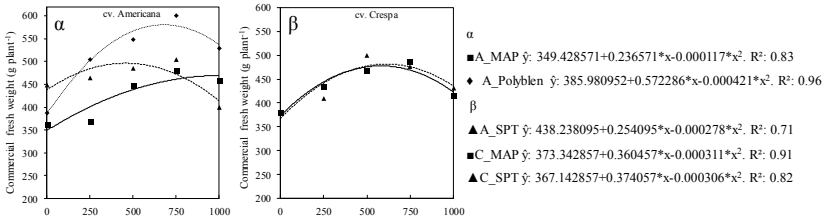

Figure 3. Fresh weight of head (FWH) of the American lettuce head - A (α) and Crespa - C (β), submitted to the phosphate sources MAP, Polyblen and SPT, as a function of the phosphorus concentration in P_2O_5. UNIFIMES, Mineiros - GO, Brazil, 2020.

Based on the results obtained by the technique of canonical variables, the respective eigenvalues and percentages of variance explained by each are presented in Table 4. The technique applied to the cultivars American (Figure α) and Crespa (Figure β) individually explained 100% of the variance of the data, when added the first two canonical pairs. Therefore, the first two canonical pairs effectively summarize the total sample variance and can be used to study the data set.

In cv. Americana, the variable PH was more associated with Polyblen fertilizer, and TLN to SPT. The variables SD and FWH were not associated with any of the phosphate sources, and the MAP source was not associated with any of the studied variables. According to the first canonical variable the characteristic of greater prominence for cv. Crespa was the PH, which, together with the characteristics of SD, CLN and FWH presented similar contributions to Can1, the phosphate sources were distant from the variables (Figure 4).

The pairs of attributes whose correlations were high (0.6-1), medium (0.31-0.59) and low (0.1-0.3) presented positive and negative signals, indicating increasing and decreasing function among variables. Therefore, scientific coherence was noted for the following positive correlation pairs: (cv. American: TLN x CLN, FWH x SD, FWH x CLN and FWH x TLN) and (cv Crespa: SD x PH, CLN x PH, TLN x PH, FWH x PH, FWH x SD, TLN x CLN, FWH x CLN and FWH x TLN), besides the negative correlation: (cv. American: NCLN x PH) and (cv Crespa: NCLN x CLN and TLN x NCLN) (Figure 5 α and

β). The other correlations were not significant. In rare works involving the phosphorus theme in lettuce crop, Kano et al. (2012) concludes that phosphorus affects the production and the number of seeds per lettuce plant, but does not affect its quality.

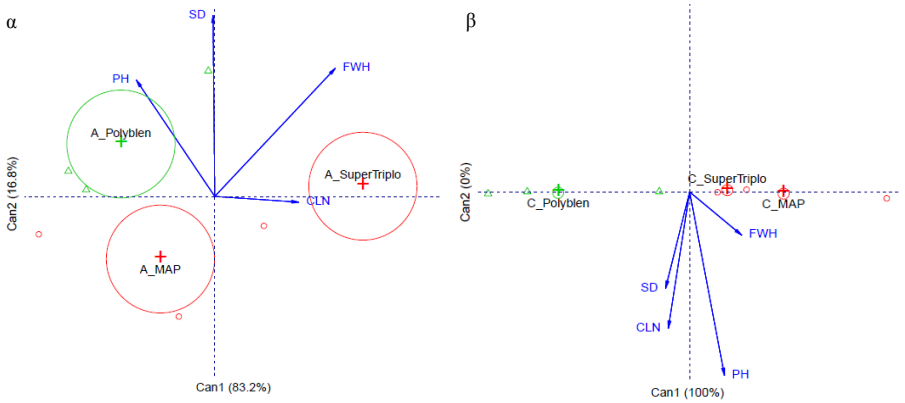

Figure 4. Analysis of canonical variables of the PH means: plant height; SD: stem diameter; CLN: commercial leaf number; and FWH: head fresh weight of American lettuce (α) and Crespa (β). Mineiros-GO, UNIFIMES, Brazil, 2020.

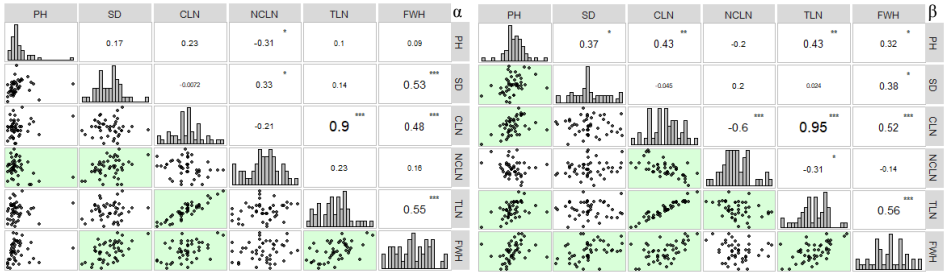

Figure 5. Correlation simple applied in the characteristics of plant height (PH), stem diameter (SD), commercial leaf number (CLN), non-commercial leaf number (NCLN), total leaf number (TLN) and fresh weight of head (FWH) of Americana (α) and Crespa (β) lettuce. Mineiros-GO, UNIFIMES, Brazil, 2020.

For Broggi et al. (2011) the low availability of phosphorus is an important limiting factor for plant growth in tropical regions, especially when combined with water deficit, causing a reduction in the photosynthetic rate. On phosphorus deficiency in lettuce Silva et al. (2011), initially found the yellowing of the edges of the old leaves and with increasing severity this symptom was transformed into a necrosis with a burn aspect.

The research demonstrated variations in the behavior of the phosphate sources listed in the different optimization trends in P2O5 reported in the estimated regressions, as well as in the lettuce genotypes. Silva et al. (2017) state that lettuce productivity and nutritional value will depend on the interaction of several factors, including plant genetics, climatic conditions, fertilization and soil conditions, among others. In this sense, further research involving the efficiency of nutritional sources available on the market and the behavior of chemical elements in lettuce should be enhanced to better guide the rural producer.

CONCLUSIONS

For high yields of cv. Americana, it is recommended to use 911 P_2O_5 ha^{-1} from MAP, 680 kg P_2O_5 ha^{-1} from Polyblen or 457 kg P_2O_5 ha^{-1} SPT. For cv. Crespa, the recommendations are 580 kg P_2O_5 ha^{-1} from MAP and 611 kg P_2O_5 ha^{-1} of SPT. The cv. Crespa gave higher fresh weight yield than cv. Americana for all phosphate sources.

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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