Phosphorus Fertilization and Water Management as Prevalent Factors in the Growth of *Crambe abyssinica*

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**Abstract:** One of the great challenges for the future will be to be able to maintain adequate water levels in the soil, in order to ensure a satisfactory development of crops. Inserted in this context, the objective of this study was to evaluate the joint effect of phosphate fertilization and water availability over the vegetative growth of *Crambe abyssinica* Hochst. The experiment was conducted in greenhouse, following a factorial scheme 4x3, with four levels of phosphorus fertilization and three levels of water availability, in a completely randomized design. The plants were cultivated for 45 days in order to gather information on their patterns of vegetative growth. The results showed the existence of interaction between the levels of phosphorus and available water in the soil for all variables. The management associating a higher level of fertilization with a greater availability of water in the soil promoted all aspects of the plant growth.

**Key words:** Crambe • Mineral nutrition • Available water • Oilseed • Phosphorus

**INTRODUCTION**

Member of the Brassicaceae family, crambe (*Crambe abyssinica* Hochst) is a vegetal species that is highlighted as an alternative for biodiesel production, due its great potential to produce vegetal oils. This species is being studied in order to improve the recommendation of agricultural traits, based mainly in the rising global concern about the depletion of non-renewable energy reserves [1].

However, there is still little information about the cultivation of crambe in Brazil, requiring scientific advances to consolidate this species as part of a sustainable energy matrix, where genetic improvement and optimization of agricultural traits, such as nutritional and hydric management, are priorities [2].

The production of energy from oil plants is an interesting alternative to help meet the projected future demands. In this context, attention should be paid to the sustainable use of agricultural land, through the improvement of management practices and the efficient use of natural resources [3].

Despite the origin being the Mediterranean region, crambe has been successfully cultivated in many different regions, with contrasting climatic conditions [1]. This fact can be related to its tolerance to drought and frost and possibility to produce satisfactorily with a short development cycle [4].

The literature indicates that one of the major limitations for agriculture in tropical soils is the phosphorus shortage, especially in regions considered marginally suitable for cultivation [5, 6]. One of the greater challenges of the future will be the maintenance of water supply, associated with the adequate nutrition, able to ensure the satisfactory growth of crops [7], therefore, it is very important today to start identifying species and genotypes that are more efficient to use of water and nutrients.

The survival of plants depends on the ability of their roots to obtain water and nutrients from the soil [8]. To ensure the growth and yield of oil crops, it is essential to supply the plants with an adequate amount of phosphorus, as these plants normally present high responsiveness to fertilization [9]. The deprivation of...
phosphorus may result in several deleterious consequences to the plant, such as starch accumulation in the chloroplast, limitation of transport of carbohydrates and decreased activity of all phosphorylation-dependent enzymes, especially those involved in the process of active nutrient absorption [10].

An insufficient supply of water in the soil will affect the metabolism and transport of solutes in the plant, having effect over the cell turgor, the regulation of stomata opening and also over the expansion of the root system, resulting in negative effects over the growth, development and crop yield [11].

According to this exposed importance, this study was conducted aiming to evaluate the associated effect of phosphate fertilization and water availability over the growth of crambe (Crambe abyssinica Hochst).

**MATERIALS AND METHODS**

**Experimental Setup:** The experiment was conducted in greenhouse, located in the Centro de Ciências Agrárias of the Universidade Federal do Espírito Santo (CCA-UFES), in the municipality of Alegre-ES, at an altitude of 136 m, with geographic coordinates 20°45’S and 41°30’W, between the months of September and October 2013.

The experiment followed a factorial scheme $4 \times 3$, with four levels of phosphorus fertilization and three levels of water availability, in a completely randomized design. Four replications were used and the experimental plot was composed by one plant per pot.

**Phosphorus Fertilization:** The soil used to fill the pots was classified as Oxisol, collected to a depth of 10 to 30 cm. It was chemically analyzed, presenting low phosphorus content (5.96 mg dm$^{-3}$), confirming its viability for studies with phosphorus fertilization. The fertility of the soil, considering all other nutrients, was corrected following the recommendations for essays in controlled environments [12].

The four levels of fertilization with $P_2O_5$ were established to provide 20%, 60%, 100% and 130% of the recommendation, giving, respectively, 0.06; 0.18; 0.30 and 0.39 g kg$^{-1}$ of the nutrient in the soil. The phosphorus fertilization was done at the time of sowing, by incorporation of nutrients in the soil. The fertilization with the others required nutrients were proceeded in three parcels, at 15, 25 and 35 days after sowing.

**Water Management:** For the levels of water availability, the level of 80% of available water (AW) was used as standard irrigation for crambe, this amount was based on preliminary observations with this species. The irrigation were managed to allow the AW to be depleted to 80%, 50% and 25% of the total AW, as levels of water availability. The irrigation was performed when the soil moisture reached the levels corresponding to each treatment, returning the water level back to the reference level.

The plants were kept in these conditions from 15 to 45 days after emergence, through daily monitoring of the moisture in the pots. The procedures to determinate the irrigation levels followed the methodology described by Bernard et al. [13], which required the hydro-physical analysis of the soil to obtain the required parameters. The hydro-physical analysis was performed according to the methodology proposed by Embrapa [14] (Table 1).

**Cultivation and Evaluations:** The seeds of Crambe abyssinica Hochst, cultivar FMS Brilhante, were provided by the MS Foundation, benefited, sterilized with solution of sodium hypochlorite (1%), washed, dried, packed and stored in refrigerator (3°C), with humidity in the mass at 10-12%, from transport to sowing. Five seeds were sown per pot (14 L of volume) and, after emergence, thinning was performed to allow the growth of only one plant per pot.

The plants were cultivated for 45 days in order to gather information on their patterns of vegetative growth, from emergency to flowering. Data about plant height (PH), number of leaves (NL), leaf area (LA), root volume (RV) and stem diameter (SD) were obtained.

Table 1: Hydro-physical attributes of the soil used in the experiment.

<table>
<thead>
<tr>
<th>Analyses</th>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Granulometric</td>
<td>Sand (%)</td>
<td>49.100</td>
</tr>
<tr>
<td></td>
<td>Silt (%)</td>
<td>5.300</td>
</tr>
<tr>
<td></td>
<td>Clay (%)</td>
<td>45.600</td>
</tr>
<tr>
<td>Density</td>
<td>Soil density (kg dm$^{-3}$)</td>
<td>1.100</td>
</tr>
<tr>
<td></td>
<td>Particles density (kg dm$^{-3}$)</td>
<td>2.710</td>
</tr>
<tr>
<td></td>
<td>Porosity (m$^3$ m$^{-2}$)</td>
<td>0.592</td>
</tr>
<tr>
<td>Hydric analyses</td>
<td>FC$^1$ (%)</td>
<td>28.800</td>
</tr>
<tr>
<td></td>
<td>PWP$^2$ (%)</td>
<td>13.570</td>
</tr>
</tbody>
</table>

(1)Proportion of soil humidity in the field capacity (tension: 0.01 Mpa); (2)Proportion of soil humidity in the permanent wilting point (tension: 1.50 Mpa).
water and observing the variation of the volume of displaced water; the stem diameter was evaluated with digital caliper (precision: 0.01 mm).

Data Analysis: The collected data were subjected to analysis of variance and, according to the presence of significant differences, the means of the levels of available water were studied using the Tukey test (5% of probability) and the means of the levels of phosphorus fertilization were studied using regression analysis (5% of probability). The analyses were performed using the statistical software SISVAR [15].

RESULTS AND DISCUSSION

There was significant effect of the interaction that plants receiving irrigation depths to renew the moisture after 50%, 75% and 100% of water consumption over plant height, number of leaves, leaf area, stem diameter and root volume of the crambe plants.

Regardless of the level of phosphorus fertilization, all variables showed greater means on the higher level of available water (Table 2), showing that the water supply near 80% of the available water on the soil promoted the growth of the plants.

Regarding the effect of the water supply in each level of fertilization with P2O5 different responses were observed in plant height, as it can be seen from Table 2. On low or high levels of fertilization, there was a clear differentiation between the means for plant height in function of the water supply: the level of 80% of AW favored the growth of plants, while the level of 25% of AW caused the plants to present smaller heights (Table 2).

With fertilization ranging between 0.18 and 0.30 g of phosphorus per kilogram of soil, plants cultivated with the lowest level of AW present higher means than plants submitted to the level of 50% of AW. However, the level of 80% of AW still favored the growth regardless of the level of fertilization (Table 2).

Similar behavior has been observed in other oil crops, such as reported by Sousa et al. [16], who studied the effects of phosphorus fertilization associated with five irrigation depths in plants of physic nut, who concluded that plants receiving irrigation depths to renew the moisture after 50%, 75% and 100% of water consumption presented better growth, even at lowest level of fertilization (135 g plant⁻¹ year⁻¹ of P2O5).

According to Hsiao [17], the water stress can affect many physiological processes, since inadequate supply of water to the cells of the meristematic regions causes them to sag, which reduces their coefficient of expansion and cell division, resulting in a several limitation of plant growth. However, it is not possible to conclude that plant growth was injured based solely on plant height, since several other features and variables are associated with the vegetative growth.

Table 2: Means of plant height (PH), number of leaves (NL), leaf area (LA), stem diameter (SD) and root volume (RV) of crambe plants, depending on the levels of available water in the soil and phosphorus fertilization.

<table>
<thead>
<tr>
<th>Variable</th>
<th>Available water (%)</th>
<th>P2O5 g kg⁻¹ soil</th>
<th>0.06</th>
<th>0.18</th>
<th>0.30</th>
<th>0.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>PH (cm)</td>
<td>80</td>
<td>63.37 a</td>
<td>67.50 a</td>
<td>76.62 a</td>
<td>89.00 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>57.12 b</td>
<td>52.00 c</td>
<td>61.75 c</td>
<td>72.12 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>49.50 c</td>
<td>60.75 b</td>
<td>72.00 b</td>
<td>68.75 c</td>
<td></td>
</tr>
<tr>
<td>NL</td>
<td>80</td>
<td>40.00 a</td>
<td>46.75 a</td>
<td>56.00 a</td>
<td>52.00 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>30.00 b</td>
<td>38.00 b</td>
<td>46.50 b</td>
<td>45.75 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>30.00 b</td>
<td>34.25 c</td>
<td>41.25 c</td>
<td>38.00 c</td>
<td></td>
</tr>
<tr>
<td>LA (cm²)</td>
<td>80</td>
<td>1.639.32 a</td>
<td>2.515.20 a</td>
<td>2.948.75 a</td>
<td>2.759.00 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>1.256.47 b</td>
<td>1.529.65 b</td>
<td>2.174.67 b</td>
<td>1.924.05 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>1.156.22 b</td>
<td>1.442.60 b</td>
<td>1.900.87 c</td>
<td>1.512.22 c</td>
<td></td>
</tr>
<tr>
<td>SD (mm)</td>
<td>80</td>
<td>10.75 a</td>
<td>10.94 a</td>
<td>11.02 a</td>
<td>11.43 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>9.53 b</td>
<td>9.10 b</td>
<td>10.07 b</td>
<td>9.04 b</td>
<td></td>
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<tr>
<td></td>
<td>25</td>
<td>9.10 b</td>
<td>9.43 b</td>
<td>9.26 c</td>
<td>9.51 b</td>
<td></td>
</tr>
<tr>
<td>RV (mL)</td>
<td>80</td>
<td>14.00 a</td>
<td>19.25 a</td>
<td>25.50 a</td>
<td>30.25 a</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50</td>
<td>10.75 b</td>
<td>15.00 b</td>
<td>22.00 b</td>
<td>27.25 b</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25</td>
<td>9.75 b</td>
<td>14.50 b</td>
<td>24.50 a</td>
<td>27.00 b</td>
<td></td>
</tr>
</tbody>
</table>

Means followed by the same letter on the column, for each variable, do not differ by the Tukey test (p>0.05).
The number of leaves followed a similar pattern in each level of fertilization, greater leafiness was observed with the increase of the level of AW up to 80% (Table 2). The presence of fewer leaves with the restriction of the water supply reduces the number of photosynthetic organs that are available for the plant metabolism, which may have direct effects over the growth, development and biomass allocation.

The development of leaf area was also favored by the level of 80% of AW. At levels of 0.06 and 0.18 g kg\(^{-1}\) of phosphorus, no differentiation was observed between 50% and 25% of AW. However, for the other levels of fertilization, it was possible to notice the more severe effect of the low water supply over the development of leaf area (Table 2). In conditions of hydric stress, the most prominent responses in plants are the reduction of leaf expansion, stomatal closure, acceleration of senescence and abscission of leaves [11]. Lacerda et al. [18] also observed higher leaf expansion on plants of castor bean due to the increase in the availability of water in the soil, promoted with the management of irrigation to maintain the level near 100% of AW.

In addition to their greater leafiness, the plants developed thicker stems due to the greater availability of water in the soil, while, in general, the size of the stems in plants subjected to levels from 25% to 50% of AW were smaller and not significantly different (Table 2). The limitation on stem diameter is possibly a result of inhibition of cell division and synthesis of cell wall, which is caused by water stress in plants [11]. There are some reports of the same behavior for other oil plants, such as the results of Medeiros et al. [19], which describe increase in stem diameter with greater availability of water to plants of physic nut.

The root volume followed the same pattern, with larger root systems from the plants grown with higher water availability. No differentiation was observed between the levels of 50 and 25% of AW and both those levels had fewer roots than the plants from the level of 80% of AW (Table 2).

The regression analyses for the growth variables as function of the fertilization with phosphorus, for each level of AW, are presented in Fig. 1. In general, all variables showed responsiveness to fertilization, since this nutrient is the most required by plants of crambe [20]. For the level of 80% of AW, the plant height had better adjustment to a linear regression model of 1st degree, indicating increase in plant growth proportional to the increase of phosphorus available in the soil, with a linear response to the fertilization. At 50% of AW, the behavior was characterized as a quadratic model (linear of 2nd degree), with a minimum point at 0.16 g of phosphorus per kilogram of soil. For the level of 25% of AW, the adjustment was also quadratic (linear 2nd degree), but fitted to a curve with maximum point at 0.35 g of P\(_{2}O_{5}\) (Fig. 1A).

![Fig 1: Regression analysis for plant height (A), number of leaves (B), leaf area (C), stem diameter (D) and root volume (E) of plants of crambe as function of the phosphorus fertilization, for each level of available water (AW).](image-url)
The height is an important trait, strongly correlated with the development of the plants, particularly for species such as crambe, which have inflorescence of raceme type. The apical meristem is subjected to the development of the plants, particularly for (1°) degree for all the levels of AW, with linear increase. Thus, a well-developed plant height and leafiness are needed to enable the creation, sustenance and maintenance of the flowering, which is directly related to the growth of grains. Therefore, the management with increased availability of water and higher levels of phosphorus become desirable, for promoting the growth of taller plants and with a more vigorous leafiness (Fig. 1A and 1B).

This behavior for the growth at 50% of AW was similar to that found by Colodetti et al. [21], studying the nitrogen fertilization in crambe. On their results, the authors reported that lowest levels of nitrogen fertilization caused the plants to develop more in height than in subsequent higher levels, with recovery of height only when the highest levels of fertilization were used.

Considering the leafiness, quadratic regression models (linear of 2nd degree) were adjusted for the three levels of AW. The points of maximum leafiness occurred at 0.33; 0.39 and 0.33 g of phosphorus per kilogram of soil for levels 80%, 50% and 25% of AW, respectively (Fig. 1B). Similar pattern was observed for leaf area, with maximum points at 0.31; 0.37 and 0.28 g kg⁻¹ of phosphorus for 80%, 50% and 25% of AW, respectively (Fig. 1C). Considering both variables, the level of 80% of AW favored the growth of leaves, enabling greater responses to the fertilization, achieving far superior results compared to the other irrigation levels (Fig. 1B and 1C).

According to Taiz and Zeiger [11], the reduction in leaf area can be considered a primary defense of plants against drought. It is known that inhibition of cell expansion slower the expansion of leaf area at the beginning of the effects of water stress. Thus, with a smaller area, the sheet will transpire less, which acts as a very efficient strategy to conserve the remaining water in the soil for a longer period of time. But this adaptation also limits the photosynthetic performance of the plant.

For stem diameter, the growth was slightly favored with increasing the fertilization under the condition of 80% of AW. There was not a noticeable effect of the fertilization in the lower levels of AW, showing that a higher level of AW may be required to allow the expression of radial growth on the stem in response to the fertilization with phosphorus (Fig. 1D).

The root volume had adjustment to linear models (1° degree) for all the levels of AW, with linear increase in RV due to the increase of fertilization. Once again, the level of 80% of AW promoted a better response on the growth, favoring the development of a larger root system than the observed in response in 50% and 25% of AW (Fig. 1E). The mutual benefice with the better supply of water and nutrient promotes the development of bulkier roots, which are able to better exploit the soil and increases the efficiency in which they access more water and nutrients.

Overall, the growth of crambe plants is promoted by phosphorus fertilization at levels ranging between 0.30 and 0.39 g kg⁻¹ associated with the management of the irrigation supplying the soil to the level of 80% of its AW.

Fig. 2 shows the more intense growth of crambe plants when cultivated higher level of available water in the soil for all the levels of phosphorus fertilization. Furthermore, higher level of AW promoted the emission of a greater number of inflorescences.

The growth of crambe in these conditions of water supply can be explained by the dynamics of the interaction between the soil colloids and phosphorus. Overall, Brazilian soils present high degrees of weathering and their attributes limit the diffusive transport of phosphorus to the roots. The adsorption of the nutrient in the colloidal particles is very intense, causing the phosphorus availability in these soils to be very limited [22]. In this scenario, water plays an important role in the system, because when soil moisture increases, the water film near the solid particles becomes thicker, decreasing the ion-colloid interaction. With the addition of water, the decreased tortuosity and viscosity increase the impedance factor, due to the greater distance between the ions and the soil colloids, contributing greatly to increase the diffusion of phosphorus in the soil solution to the plant roots.

This direct relationship between water content in the soil and the phosphorus diffusion has been reported by several authors [5, 22-25], being largely related to the growth and crop yield in tropical soils with high clay content and high degree of weathering.

The literature reports cases in which increasing the water content in the soil is enough to promote the diffusive flow of phosphorus to the roots, even when the supply of this nutrient is not increased in the system [23]. This fact may explain the more vigorous growth of the crambe plants in the managements with higher water content in the soil, regardless of the phosphorus fertilization.
CONCLUSIONS

The water availability and phosphate fertilization interact with each other and affects the growth of crambe plants.

It is possible to promote the development of crambe plants through the management of the nutrition and irrigation, supplying an adequate level of available water in the soil to increase the response of the plants to the fertilization with phosphorus.

REFERENCES


