Root growth and nutrition of cotton as affected by phosphorus and liming
Effet du phosphore et du chaulage sur la croissance racinaire et la nutrition du coton

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INTRODUCTION

Cotton root length increases up to flowering (80-90 days after plant emergence). After this there is not a significant increase in length but there is an increase in root dry matter (Nayakekorala and Taylor, 1990). The root length density is low when compared to other crop species, which leads to a low exploitation of the soil nutrients (Brouder and Cassman, 1990).

The root growth pattern is genetically controlled but can be modified by the environment, as well as by soil characteristics (Taylor and Arkin, 1981). Besides the physical characteristics of the soil, toxic Al, low Ca and low P are known to affect root growth (Adams and Pearson, 1970; Barber, 1984; Rosolem et al., 1995). These chemical constraints can be overcome by liming, which neutralizes toxic Al, increases Ca levels and sometimes can make P more available to plants in tropical intemperized soils (Raij, 1991).

Root growth of cotton was reduced when the soil Ca saturation was below 17% (Adams and Moore, 1983). Rosolem et al. (1996) noticed no increase in cotton root growth when the soil base saturation was raised from 40 to 52 % (Ca contents increased from 16 mm$_{(c)}$ kg$^{-1}$ to 20 mm$_{(c)}$ kg$^{-1}$), but in the higher base saturation the roots were able to penetrate in compacted layers of the soil. However, when the base saturation was increased to 67 %, and Ca contents to 26 mm$_{(c)}$ kg$^{-1}$, there was a decrease in root growth due to Zn deficiency. Positive effects of Ca on root growth were observed in peanuts (Caires and Rosolem, 1991) and soybean (Rosolem et al., 1995) when the soil had 15 mm$_{(c)}$ dm$^{-3}$ of Ca. The root surface of two corn hybrids were also increased when soil Ca was increased from 6 mm$_{(c)}$ dm$^{-3}$ to 16 mm$_{(c)}$ dm$^{-3}$ (Rosolem et al., 1994).

Phosphorus uptake is dependent on root length, diameter and surface area in contact with the soil (Anghinoni and Barber, 1980). The soil P content also affect root morphology (Zhang and Barber, 1992). An increase in soil P can lead (Hajabbasi and Shumacher, 1994) or not (Rosolem et al., 1994) to an increase in corn root length and surface. The corn root morphology response to soil P depends also on the cultivar (Rosolem et al., 1994).

The purpose of this study was to evaluate the initial growth and nutrition of cotton plants as related to root morphology and growth in response to phosphorus and lime application.
MATERIAL AND METHODS

The experiment was conducted in greenhouse conditions in Botucatu, São Paulo, Brazil, in 4 L pots containing a Dark Red Latosol (Acrortox, 20% clay, 72% sand). Originally the soil showed pH (CaCl$_2$) 4.0, 19 g kg$^{-1}$ of Organic Matter, 3.2 mg kg$^{-1}$ of P (resin), 7 mmol$_{(c)}$ kg$^{-1}$ of Ca, 3 mmol$_{(c)}$ kg$^{-1}$ of Mg and 0.5 mmol$_{(c)}$ kg$^{-1}$ of K. Burnt dolomitic lime (450 g kg$^{-1}$ of CaO and 150 g kg$^{-1}$ of MgO) was applied at 2.24, 4.48 and 6.72 g pot$^{-1}$. After a 35-day period of wet incubation, phosphorus was added at 0.0, 50, 100 and 150 mg kg$^{-1}$ as KH$_2$PO$_4$ and NH$_4$H$_2$PO$_4$. After 10 days the pots were fertilized with 100 mg kg$^{-1}$ of K as KCl, 30 mg kg$^{-1}$ of N as urea, 2 mg kg$^{-1}$ of B as H$_3$BO$_3$ and 3 mg kg$^{-1}$ of Zn as ZnCl$_2$ and 4 pre-germinated (germination chamber, 25/30 ºC, 72 hours) cotton (cv. IAC 22) seeds were planted to each pot. One week after plant emergence, the pots were thinned to 2 plants.

The soil was sampled and analyzed at planting (Table 1).

The pots were watered daily to maintain soil water around 80% of the water holding capacity. The average temperature in the greenhouse during the experiment was 23.6 ºC and the average Relative Humidity was 78%. The plants were grown for 42 days.

At harvest, the plants were separated in tops and roots. The roots were separated from the soil with tap water over a 0.5 mm screen. Dry weight of the roots was determined in a subsample. In another subsample we determined root length (Tennant, 1975), diameter and surface (Hallmark and Barber, 1984). The tap root was separated from the secondary and analyzed separately. The top and root tissues were ground, wet digested and analyzed for P, K, Ca and Mg contents.

The experimental design was a factorial 3 x 4 with 4 replicates in randomized blocks.

RESULTS AND DISCUSSION

Liming caused an increase in pH, soil Mg, Ca, base saturation and Ca saturation. The potential acidity (H$^+$ + Al$^{3+}$) was decreased (Table 1). In this soil, at a pH (CaCl$_2$) of 4.8 Al should not be in toxic concentrations (Raij, 1991).

Table 1: Selected soil chemical characteristics at planting time.

<table>
<thead>
<tr>
<th>Lime (g kg$^{-1}$)</th>
<th>pH</th>
<th>H$^+$ + Al$^{3+}$</th>
<th>Mg (mmol$_{(c)}$ kg$^{-1}$)</th>
<th>Ca (mmol$_{(c)}$ kg$^{-1}$)</th>
<th>Base Saturation (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.24</td>
<td>4.8</td>
<td>40</td>
<td>11</td>
<td>18</td>
<td>24</td>
</tr>
<tr>
<td>4.48</td>
<td>5.2</td>
<td>32</td>
<td>15</td>
<td>24</td>
<td>32</td>
</tr>
<tr>
<td>6.72</td>
<td>5.5</td>
<td>26</td>
<td>20</td>
<td>29</td>
<td>36</td>
</tr>
</tbody>
</table>

The application of 0, 50, 100 and 150 mg kg$^{-1}$ of P resulted in 14, 34, 83 and 88 mg kg$^{-1}$ of soil P, respectively, by planting time.

The only P x lime significant interaction was observed in K nutrition. As regarding the other parameters, the effects of P and lime are presented and discussed separately.

There was no effect of liming on dry matter yield, root length and surface (Table 2), but the root diameter was decreased from 0.33 to 0.30 mm with the increase in soil Ca. The smallest lime rate increased the Ca content of the soil to 18 mmol$_{(c)}$ kg$^{-1}$, what was not
expected, since the original content was 7 mmol$_{(c)}$ kg$^{-1}$. Ca saturation was increased to 24 %, higher than the threshold of 17 % defined by Adams and Moore (1983).

In a similar soil, Rosolem et al. (1996) found that an increase in the soil Ca content over 16 mmol$_{(c)}$ kg$^{-1}$, corresponding to a soil base saturation over 40%, led to an increase in cotton root growth only when the soil was compacted. In corn, increases in root surface were noticeable when Ca contents in the soil were raised up to 16 mmol$_{(c)}$ kg$^{-1}$, with no further change when Ca was increased up to 54 mmol$_{(c)}$ kg$^{-1}$ (Rosolem et al., 1994). In this experiment, cotton roots were less responsive to Ca than soybeans or peanut roots (Caires and Rosolem, 1991; Rosolem et al., 1995).

<table>
<thead>
<tr>
<th>Lime Dry matter yields</th>
<th>Root characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Root</td>
</tr>
<tr>
<td>g kg$^{-1}$</td>
<td>g plant$^{-1}$</td>
</tr>
<tr>
<td>2.24</td>
<td>0.44</td>
</tr>
<tr>
<td>4.48</td>
<td>0.41</td>
</tr>
<tr>
<td>6.72</td>
<td>0.41</td>
</tr>
<tr>
<td>F test</td>
<td>ns$^{(1)}$</td>
</tr>
</tbody>
</table>

(1) ns - not significant  
(2) * - significant (P< 0.05)

There was no effect of liming on the amount of P, Ca and Mg uptake per unit of root surface.

There was an increase in root and shoot dry mater yields due to P fertilization with the increase in P contents from 14 to 83 mg kg$^{-1}$, which corresponds to the application of 100 mg kg$^{-1}$ of P (Fig. 1). The increase in shoot dry matter was proportionally higher in the shoots than in the roots, resulting in a higher shoot/root ratio in the higher soil P contents, respectively 2.5, 3.1, 3.4 and 3.6 with the application of 0, 50, 100 and 150 mg kg$^{-1}$ of P.

Root length and surface were also increased by P fertilization up to 83 mg kg$^{-1}$ of P in the soil (Fig. 2). Root diameter was increased from 0.317 to 0.328 with P rates up to 100 mg kg$^{-1}$, and than decreased to 0.298 with the highest P rate. The increase in root surface was mainly due to the increase in length, because the curves are very similar.

An increase in root length due to P fertilization was expected (Brouder and Cassman, 1994), but the root length and diameter response depends on the amount of available P and also on the cultivar (Hajabbasi and Shumacher, 1994).
On the other hand, P concentration in the roots and shoots were increased by P fertilization up to 50 mg kg\(^{-1}\) (33 mg kg\(^{-1}\) in the soil), with no further increases in the higher P rates (Fig. 3).

P fertilization led to a higher efficiency in nutrient acquisition by the cotton plants (Table 3).

Looking at Fig. 3 and Table 3, it can be inferred that, at low soil P contents, the response to P was due to an increase in root length and in the efficiency of P absorption. At the higher P contents, the increase in nutrient uptake was related mainly to root growth.

With low soil P, the transport of the nutrient to the root surface was limiting the process and the root growth rate was not big enough to compensate for the low P levels. The plants were P deficient, limiting the amount of the available energy for ion uptake in general. Phosphorus fertilization causes an increase in the P concentration in the soil solution, in the buffer power of the soil and also in the effective diffusion coefficient (Barber, 1984). At high soil P levels the transport the nutrient to plant roots allowed for an uptake rate close to Imax (Barber 1984: maximum influx of nutrients), overcoming the P deficiency and allowing for high uptake rates of P and also of the other nutrients. In this case the nutrient uptake was closely related to root growth (Fig. 2 and 3, Table 3).

Table 3: Phosphorus, calcium and magnesium accumulation per unit of root surface as affected by P fertilization and potassium accumulation as affected by P fertilization and lime application.

<table>
<thead>
<tr>
<th>P applied (mg kg(^{-1}))</th>
<th>P Ca Mg</th>
<th>Lime = 2.24</th>
<th>Lime = 4.48</th>
<th>Lime = 6.72</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>7.2c(^{(1)})</td>
<td>34.1b</td>
<td>199.8d</td>
<td>291.6c</td>
</tr>
<tr>
<td>50</td>
<td>14.8b</td>
<td>39.8ab</td>
<td>270.3c</td>
<td>373.2b</td>
</tr>
<tr>
<td>100</td>
<td>19.6a</td>
<td>48.7a</td>
<td>547.7a</td>
<td>401.8b</td>
</tr>
<tr>
<td>150</td>
<td>19.4a</td>
<td>49.7a</td>
<td>491.4b</td>
<td>452.3a</td>
</tr>
</tbody>
</table>
Potassium uptake per unit of root volume was increased by P fertilization up to 100 mg kg\(^{-1}\), and was decreased by liming at the higher P rates (Table 3). The Ca x K interaction is well known. At the lower P rates there was a general limitation to nutrient uptake, which may have avoided the interaction. On the other hand, we could not find an explanation for the decrease in K uptake with the highest P rate, what was observed in the lowest and highest lime rates.

CONCLUSIONS

Soil Ca contents of 18 mmol(c) kg\(^{-1}\) and higher provided for a good root and shoot development of cotton plants.

Phosphorus concentrations in cotton shoots and roots were increased when the soil P was increased up to 33 mg kg\(^{-1}\), but the maximum root length, root surface and root and shoot dry matter yields were observed only when soil P contents were raised to 83 mg kg\(^{-1}\), when the plants showed a higher shoot/root ratio.

Besides an increase in root length and surface, there was an increase in P uptake efficiency as soil P was increased.

REFERENCES


Keywords: Lime, nutrient bioavailability, soil calcium, soil phosphorus, root length
Mots clés : calcaire, biodisponibilité des éléments, calcium du sol, phosphore du sol, longueur des racines