LONG TERM EXPERIMENTS WITH REACTIVE PHOSPHATE ROCKS FOR GRAIN CROPS IN CERRADO SOILS

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Prevalence of very-low and low fertility soils

Source: Embrapa (1980)
Phosphorus fertilization

Corrective fertilization $\Rightarrow$ 60 - 240 kg/ha $P_2O_5$
<table>
<thead>
<tr>
<th>COUNTRY</th>
<th>RESERVES</th>
<th>% RESERVES</th>
</tr>
</thead>
<tbody>
<tr>
<td>MOROCCO</td>
<td>50.0</td>
<td>74.9</td>
</tr>
<tr>
<td>CHINA</td>
<td>3.7</td>
<td>5.5</td>
</tr>
<tr>
<td>ALGERIA</td>
<td>2.2</td>
<td>3.3</td>
</tr>
<tr>
<td>SYRIA</td>
<td>1.8</td>
<td>2.7</td>
</tr>
<tr>
<td>SOUTH AFRICA</td>
<td>1.5</td>
<td>2.2</td>
</tr>
<tr>
<td>BRAZIL</td>
<td>0.3</td>
<td>0.4</td>
</tr>
<tr>
<td>OTHERS</td>
<td>7.3</td>
<td>10.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>66.7</td>
<td>100</td>
</tr>
</tbody>
</table>

**WORLD PHOSPHORUS RESERVES**

## P sources in Brazil – 2009 to 2012

<table>
<thead>
<tr>
<th>SOURCES</th>
<th>BRAZILIAN AGRICULTURE - %</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP &amp; SSP</td>
<td>53.5</td>
</tr>
<tr>
<td>MAP &amp; DAP</td>
<td>44.0</td>
</tr>
<tr>
<td>RPR</td>
<td>1.7</td>
</tr>
<tr>
<td>Others</td>
<td>0.8</td>
</tr>
</tbody>
</table>

*Source: adapted from Cunha et al. (2014)*
P fertilizer rates in Brazil

Soybeans: 78 kg/ha $\text{P}_2\text{O}_5$
Corn: 45 kg/ha $\text{P}_2\text{O}_5$

$R^2 = 0.88$

Source: adapted from Cunha et al. (2014)
MAP international prices

Yearly averages

INCREASE OF 180% IN 12 YEARS

* 2014 average (January to May)

Source: Siacesp (Boletins Green Market e FMB)
Reactive phosphate rock

- At least 30% of total P$_2$O$_5$ soluble in citric acid 2% (1:100), analized in unground sample.

- At least 55% of total P$_2$O$_5$ soluble in formic acid 2% (1:100), analized in unground sample.
Guaranteed analysis:

$P_2O_5$ total = 29%
$P_2O_5$ sol. citric acid = 48% of total $P_2O_5$
$P_2O_5$ sol. formic acid = 70% of total $P_2O_5$
• Fertilizer characteristics
• Fertilizer management
FERTILIZER CHARACTERISTICS
P rate $\rightarrow 160 \text{ kg/ha } P_2O_5$ in the 1st year

Very clayey oxisol – Conventional till soybeans

### PHOSPHORUS SOURCE

<table>
<thead>
<tr>
<th></th>
<th>RAE/CROP 1st</th>
<th>RAE/CROP 2nd</th>
<th>RAE/CROP 3rd</th>
<th>Total yield t/ha</th>
</tr>
</thead>
<tbody>
<tr>
<td>N. Carol. (unground)</td>
<td>63</td>
<td>138</td>
<td>167</td>
<td>4.62</td>
</tr>
<tr>
<td>N. Carol. (ground)</td>
<td>96</td>
<td>112</td>
<td>114</td>
<td>4.56</td>
</tr>
<tr>
<td>TSP</td>
<td>100</td>
<td>100</td>
<td>100</td>
<td>4.37</td>
</tr>
</tbody>
</table>

Source: Rein et al. (1994)
## REACTIVITY

**Clayey oxisol – Conventional till – 240 kg/ha P$_2$O$_5$**

<table>
<thead>
<tr>
<th>RPR source</th>
<th>Total P$_2$O$_5$</th>
<th>P$_2$O$_5$ solubility</th>
<th>Soybean crops</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>2% Citr. acid (1:100)</td>
<td>2% Form. acid (1:100)</td>
</tr>
<tr>
<td>Arad</td>
<td>32.3</td>
<td>35</td>
<td>58</td>
</tr>
<tr>
<td>Algeria</td>
<td>29.0</td>
<td>37</td>
<td>68</td>
</tr>
<tr>
<td>N. Carolina</td>
<td>29.8</td>
<td>44</td>
<td>76</td>
</tr>
<tr>
<td>Morocco 1</td>
<td>31.1</td>
<td><strong>32</strong></td>
<td><strong>58</strong></td>
</tr>
<tr>
<td>Morocco 2</td>
<td>30.8</td>
<td>35</td>
<td>62</td>
</tr>
<tr>
<td>Morocco 3</td>
<td>26.4</td>
<td>37</td>
<td>64</td>
</tr>
<tr>
<td>Gafsa</td>
<td>28.2</td>
<td>45</td>
<td>75</td>
</tr>
<tr>
<td>TSP</td>
<td>43.8</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>
Clayey oxisol - conventional till soybeans
7 RPRs - 240 kg/ha P$_2$O$_5$ applied only in the first year

RAE - cumulative yields of the 6 crops: ranged from 88% to 104%
RAE calculated from cumulative yields of the first three crops

Formic acid
\[ y = -48.2 + 2.1x \]
\[ r^2 = 0.83 \]

Citric acid
\[ y = -33.5 + 3.3x \]
\[ r^2 = 0.85 \]
MANAGEMENT
Surface broadcast limestone and P fertilizers
Effects on pasture (ryegrass/white clover)

Dry matter, t/ha

Source: Xavier, F.M. et al. 1995 – UFSM
Agronomic effectiveness
Soil P availability
Reactive phosphate rocks
Relative agronomic effectiveness (RAE) in the 1st year for annual crops in Cerrado soils (broadcast incorporated)

<table>
<thead>
<tr>
<th>RPR</th>
<th>RAE - %</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MS</td>
<td>DF</td>
<td>MG</td>
<td></td>
</tr>
<tr>
<td>Gafsa</td>
<td>54</td>
<td>54</td>
<td>81</td>
<td></td>
</tr>
<tr>
<td>N. Carolina</td>
<td>42</td>
<td>63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arad</td>
<td>39</td>
<td></td>
<td>60</td>
<td></td>
</tr>
<tr>
<td>Morocco</td>
<td></td>
<td></td>
<td>70</td>
<td></td>
</tr>
</tbody>
</table>

Source: Sousa et al. (1999)
GAFSA RPR - 240 kg/ha $P_2O_5$ the 1st year; Conventional till soybeans

Source: Sousa et al. (1999)
Soil P availability
Mehlich-1 and Bray-1 extractants

Source: Sousa et al. (1999)
Soil testing – P extractants

TSP

TSP and RPR

Source: Sousa & Rein (2009)
Management of soil and fertilizer P

- Corrective (build-up) fertilization
- Maintenance fertilization
RPR in corrective fertilization (broadcast incorporated) – **No-till soybeans/corn**

Source: Sousa et al., unpublished (2014).
Corrective (build up) fertilization - 240 kg P$_2$O$_5$/ha
15 years – No-till soybeans/corn

<table>
<thead>
<tr>
<th>Corrective fertilization</th>
<th>Cumulat. yields</th>
<th>Yields</th>
<th>Gross margin</th>
<th>Fertilizer costs</th>
<th>Benefit / cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Soy (9)</td>
<td>Corn (6)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>No</td>
<td>95.7</td>
<td>3.22</td>
<td>13.34</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TSP</td>
<td>99.2</td>
<td>3.55</td>
<td>13.44</td>
<td>3,170.00</td>
<td>720.00</td>
</tr>
<tr>
<td>RPR</td>
<td>101.0</td>
<td>3.61</td>
<td>13.69</td>
<td>4,126.00</td>
<td>540.00</td>
</tr>
</tbody>
</table>

Maintenance fertilization: 80 kg/ha/year P$_2$O$_5$ as TSP

*Source: Sousa et al., unpublished (2014)*
Clayey oxisol, no-till system - adequate P level
Maintenance fertilization: 50 kg/ha/year P$_2$O$_5$

<table>
<thead>
<tr>
<th>Source</th>
<th>Soy (8 crops)</th>
<th>Corn (7 crops)</th>
<th>Cost of P</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>3.60</td>
<td>10.82</td>
<td>2,250.00</td>
</tr>
<tr>
<td>RPR</td>
<td>3.42</td>
<td>10.43</td>
<td>1,687.50</td>
</tr>
</tbody>
</table>

Net margin (RPR - TSP) = R$ -2,339.40 + R$ 562.50 = R$ -1,776.99

Source: Sousa, D.M.G. unpublished (2014)
RPR management in no-till soy/corn (millet cover crop)
Clayey oxisol with adequate P availability
80 kg $P_2O_5$ ha$^{-1}$ year$^{-1}$ (banded in the seed furrow)

![Graph showing grain yield (t/ha) over 15 crops, with crop yields differentiated by treatment: RPR at planting, RPR anticipated (millet), and TSP at planting.](source: Sousa, D.M.G., unpublished (2014)).
## Economic analysis

<table>
<thead>
<tr>
<th>Fertilization</th>
<th>Total 15 years</th>
<th>Soy (9)</th>
<th>Corn (6)</th>
<th>Revenue RPR-TSP</th>
<th>Cost saving w/ RPR</th>
<th>Net margin</th>
</tr>
</thead>
<tbody>
<tr>
<td>TSP</td>
<td>99.0</td>
<td>58.9</td>
<td>186.7</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>RPR sowing</td>
<td>94.9</td>
<td>54.6</td>
<td>181.7</td>
<td>-2,884.00</td>
<td>900.00</td>
<td>-1,984.00</td>
</tr>
<tr>
<td>RPR millet</td>
<td>99.2</td>
<td>59.3</td>
<td>186.6</td>
<td>237.00</td>
<td>900.00</td>
<td>1,137.00</td>
</tr>
</tbody>
</table>

TSP: R$ 3.00; RPR: R$ 2.25 / kg P$_2$O$_5$

*Source: Sousa et al., unpublished data (2014)*
Fertilizer placement and soil tillage effects
Clayey oxisol – 80 kg $\text{P}_2\text{O}_5$ ha$^{-1}$ year$^{-1}$
Very-low soil extractable P – Tilled (disk plow)

Cumulative yields (17 years):
RPR Broadcast = 90.1 t/ha; RPR banded = 86.8 t/ha; TSP banded = 88.6 t/ha
Clayey oxisol – 80 kg P$_2$O$_5$ ha$^{-1}$ year$^{-1}$
Very-low soil extractable P – No-till

Cumulative yields (17 years):
RPR Broadcast = 90.2 t/ha; RPR banded = 87.6 t/ha; TSP banded = 96.6 t/ha
6th year Soybeans

No-till RPR band
2.9 t ha$^{-1}$

No-till RPR broad
2.8 t ha$^{-1}$

Tilled RPR band
3.0 t ha$^{-1}$

Tilled RPR broad
3.1 t ha$^{-1}$
11th year Corn

No-till RPR band 10.5 t ha\(^{-1}\)

No-till RPR broad 11.8 t ha\(^{-1}\)

Tilled RPR band 10.7 t ha\(^{-1}\)

Tilled RPR broad 11.8 t ha\(^{-1}\)

90 cm

75 cm
Clayey oxisol – 80 kg P$_2$O$_5$ ha$^{-1}$ year$^{-1}$
Very-low soil extractable P – No-till
TRIPLE SUPERPHOSPHATE

REACTIVE PHOSPHATE ROCK

8th crop

Source: adapted from Santos (2009)
RESIDUAL EFFECT
Long term experiments in clayey oxisols

240 kg ha\(^{-1}\) P\(_2\)O\(_5\)
Long term experiments in clayey oxisol
80 kg ha\(^{-1}\) year\(^{-1}\) P\(_2\)O\(_5\) for 17 years (soy/corn)
Long term experiments in clayey oxisol

0 kg ha\(^{-1}\) year\(^{-1}\) P\(_2\)O\(_5\) for 3 years (corn)

Tillage

No-Tillage

Cumulative yield, t/ha

Residual P\(_2\)O\(_5\) in soil, kg/ha
Similarity dendrogram of the bacterial community structure in the very clayey oxisol 16th crop
Differences in the functional structure of bacterial community in the very clayey oxisol 16th crop
The agronomic effectiveness of RPRs during the first years after broadcast application with incorporation in Cerrado oxisols is directly related to the solubility in citric and formic acids. In the medium term (>3 years), the residual effects of the least soluble RPRs are equivalent or even slightly higher than water-soluble sources and the most soluble RPRs.
RPRs are suitable for corrective (build up) fertilization of Cerrado soils. RPRs can also be recommended for maintenance fertilization of grain crops in soils with adequate (near or above critical level) P, being more effective under conventional tillage. The agronomic effectiveness is enhanced when the application of RPR is anticipated to the winter cover crop in no-till grain production systems.
CONCLUSIONS

Mehlich-1 and resin extractants as used in Brazil overestimate the availability of soil P when RPRs are used, which does not occur with the Bray 1 extractant.