Phosphorus mobilization at plot and field scale

Elisabetta Barberis

Di.VA.PRA – University of Torino - Italy
Mobilization is the initiation of P movement:

- **Mechanisms**
  - Accumulation
  - Mobilization
  - Transport

- **Critical areas**
  - Source factors
    - P forms
    - Soil properties
    - Solution properties
  - Transport factors

- **P transfer** from soil to water
Processes for mobilization

- Solubilization
- Detachment

![Image of wet field](image-url)
Solubilization → Transfer of P from a solid phase to a water phase

Soluble P < 0.45 µm

inorganic
organic
condensed
colloidal

OM and biomass

mineralization
organization

P in solution

dissolution
precipitation

Secondary minerals (P-Ca, Fe e Al)

Primary minerals

ox-Fe /Al
Clay minerals

Solubilization

Dissolution
Precipitation
Mineralization
Organic

Transfer of P from a solid phase to a water phase
Detachment → Particulate P >0.45\(\mu\)m
Soil with low P sorption capacity

Soil properties

1. Texture: sandy
2. Low specific surface area
3. Poor in P sorbing constituents

Leaching through sandy soils towards the ground water accounted for about 85-90% of the P losses from the agricultural land. (Breeuwsma and Silva; 1992)
Soil with high P sorption capacity

**Soil properties**

1. **Texture**: clay
2. **High specific surface area**
3. **Rich in P sorbing constituents**

**Solubilization**

1. *in the humid temperate regions*: poorly crystalline Fe and Al oxides and organic complexes (van der Zee et al., 1990)
2. *in the Mediterranean region*: crystalline Fe oxides, carbonates and clay minerals (Peña & Torrent, 1990)
In agricultural soils P tends to accumulate in the topsoil

<table>
<thead>
<tr>
<th>P level</th>
<th>P addition</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0</td>
</tr>
<tr>
<td>B</td>
<td>Replacement of P (R)</td>
</tr>
<tr>
<td>C</td>
<td>(R) + 15 kg P ha(^{-1}) y(^{-1})</td>
</tr>
<tr>
<td>D</td>
<td>(R) + 30 kg P ha(^{-1}) y(^{-1})</td>
</tr>
</tbody>
</table>

Prediction of soil P susceptible to transfer to water in soluble forms.

Approaches

• Use of soil test P (STP)
• Evaluation of P sorption properties of soils
• Quantification of P in the soil solution

Experimental methodologies

Tested measuring P concentration and/or P forms in leachate

1. Intact soil cores
2. Homogenized soil columns
3. Lysimeter
4. Porous cup
5. Drainage water
6. Surface runoff
1. Solubilization: use of STP

The amount of P released from soil solid phases to solution is dependent on soil P status

Relathionship between STP and RP

Heckrath et al. 1995
McDowell and Condron, 1999
Hesketh and Brookes, 2000

.............................................

Olsen P (ppm)

CaCl$_2$-RP µg L$^{-1}$

Orup
S. Ugglarp
Ekebo
Fjärdingslöv
Örja
Högåsa
Fors
Bjertorp
Klostergården
Kungsängen

Orup, S. Ugglarp, Ekebo, Fjärdingslöv, Örja, Högåsa, Fors, Bjertorp, Klostergården, Kungsängen

The amount of P released from soil solid phases to solution is dependent on the degree of P sorption saturation (DPSS)

$$DPSS\ (\%) = \frac{\text{sorbed P}}{\text{P Sorption Capacity (PSC)}} \times 100$$

$$DPSS\ (\%) = \frac{P_{ox}}{\alpha (\text{Fe}_{ox} + \text{Al}_{ox})} \times 100$$

van der Zee et al. (1987)
The amount of P released from soil solid phases to solution is dependent on the degree of P sorption saturation.

\[
\text{DPSS (\%)} = \frac{\text{sorbed P}}{\text{PSC}} \times 100
\]
2. Solubilization: evaluation of PSC

\[ y = 0.65x - 0.07 \]

\[ r^2 = 0.94*** \]
Extraction of soils at different solution:soil ratio

1:1
- Simulate leaching conditions

10000:1
- Simulate runoff or interactions between soil and rain

Water
CaCl₂ 0.002-0.01 M

1.2:1 versus RP in leachates
Chapman et al., 1997

100:1 versus RP in runoff
Yli-Halla et al. 1995
Detachment of soil particles and colloids with attached P is mainly due to forces exerted by moving water and repulsive forces between colloidal particles.
Particulate P >0.45µm

\[ P_{\text{loss}} = \frac{\text{Mass of P}}{\text{Mass of erodible soil}} \times \frac{\text{Mass of erodible soil}}{\text{Volume}} \]

P concentration of soil particles

the loss of soil
Physical factors:
- rain splash energy
- slaking forces
- shear forces of overland flow

Chemical factors
- properties of dispersible particles
- properties of soil solution
Dispersion/flocculation behavior of colloids depends on their charge
### Particles Charge

<table>
<thead>
<tr>
<th>Material</th>
<th>Charge at Soil pH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>Negative at all</td>
</tr>
<tr>
<td>Clay minerals</td>
<td>Negative at all</td>
</tr>
<tr>
<td>Fe and Al oxides</td>
<td>Positive at pH &lt; PZC, Negative at pH &gt; PZC</td>
</tr>
</tbody>
</table>

#### Detachment

- **pH < PZC**
- **pH = PZC**
- **pH > PZC**

- **goethite**
- **caolinite**
Surface charge

- monovalents

\[ \text{pH} < \text{pzc} \]

- polivalent

Ionic strength

Dispersion
Effects of anions adsorption on surface properties

The new surface is more negative
Sorption of Pi and IHP on goethite
Effect on Zeta Potential ($\zeta$)
Detachment

Percentage of IHP saturation

Zeta potential (mV)

0.5 - 0.8 µm

0.5 - 2 µm

Celi and Barberis 2005
Detachment

Effects of P application rate on water dispersible clay

P rate (mg kg\(^{-1}\))

Water dispersible clay g (kg\(^{-1}\))

PSC = 52 mg kg\(^{-1}\)

Colloidal P in suspension mg L\(^{-1}\)

Sorbed P (ultra-centrifuged) mg kg\(^{-1}\)

Adapted from Zhang, He, Calvert, Stoffella, 2003. Soil Sci.

Prediction of soil P susceptible to transfer to water in particulate forms.

**Approaches**

- Wet sieving
- Dispersibility of a single aggregate
- Percolation stability test
- Erodibility tests
- Soil dispersibility tests

Physically based
Total soil P content is not a good index of particulate P

PER = \frac{\text{Total P in clay}}{\text{Total P in soil}}

Barberis and Withers 2002
Prediction of soil P susceptible to transfer to water in particulate forms.

- **Soil dispersibility tests**
  - Measure of suspended solids and P
  - Calibration with indoor/outdoor simulation


**Detachment**

**Suspended sediment**

- Event 1
- Event 2
- TF, event 1
- TF, event 2

\[ y = 3.9x - 0.67 \]

\[ r^2 = 0.75 \]

**Amounts dispersed in test (g)**

**DESPRAL test**

Gentle water dispersion test at solution to soil ratio 20:1

**Total P**

\[ y = 2.63x - 0.43 \]

\[ r^2 = 0.67 \]

**Amounts dispersed in runoff (mg)**

Correlations between Total suspended sediment (TSS) and detached P and soil properties

\[ \ln \text{TSS} = -1.319 + 0.378(\ln \text{clay}) + 0.017\times(\text{silt}) - 0.151(\ln \text{Olsen P}) \]

**TP detached**

**Total soil Olsen P**

- Clay
- pH
- Organic matter

NOT or poorly Correlated with

Udeigwe et al. 2007; Withers et al. 2007; Borda et al. 2010
Thank you