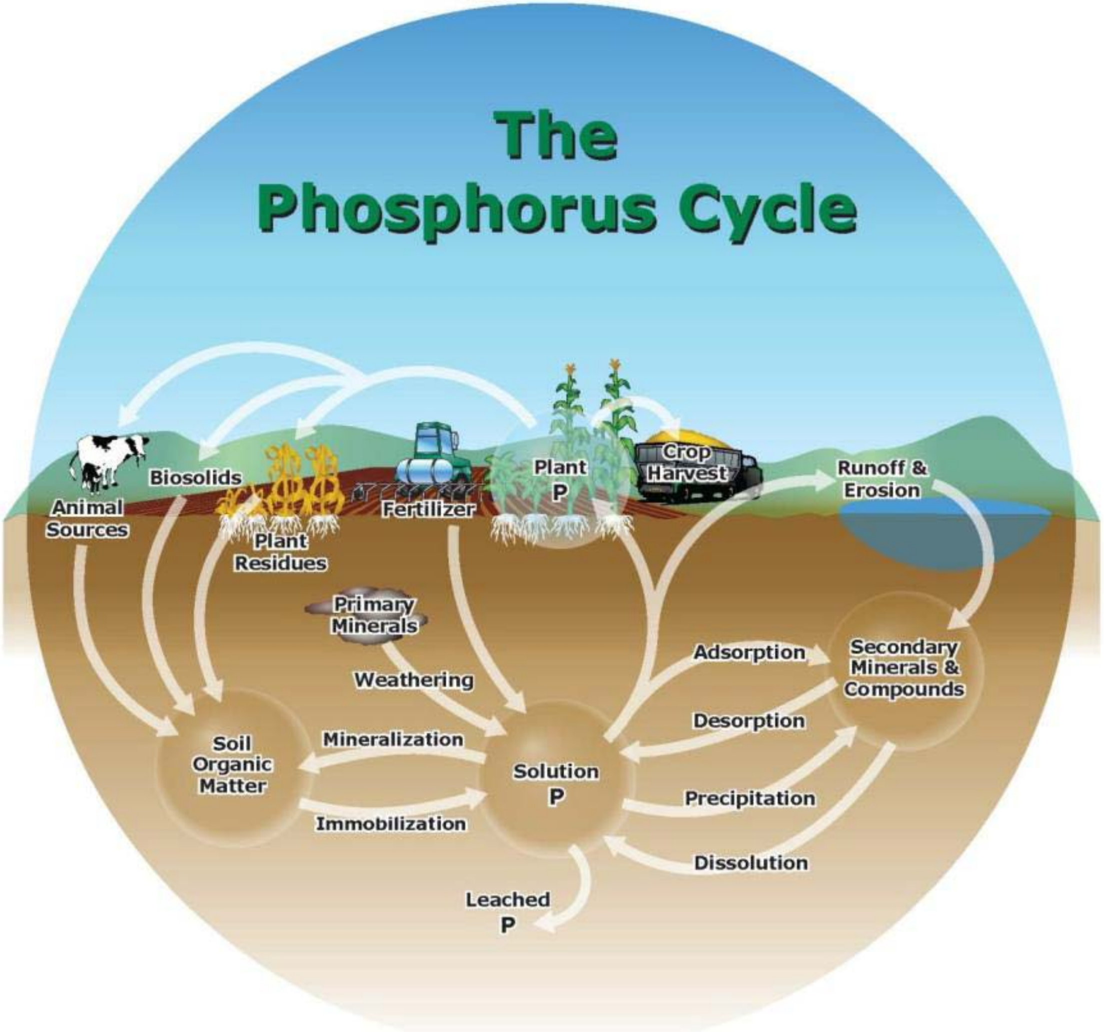
IPNI
International
Plant Nutrition
Institute

Phosphorus Fertilizer Production and Technology

Phosphorus (P) Cycling in Crop Production Systems



P is Essential for Plant Nutrition

- Taken up mostly as phosphate ($H_2PO_4^-$ and HPO_4^{2-})
- Involved in photosynthesis, energy transfer, cell division and enlargement
- Important in root formation and growth
- Improves the quality of fruit and vegetable crops
- Is vital to seed formation
- Improves water use
- Helps hasten maturity


P deficient corn

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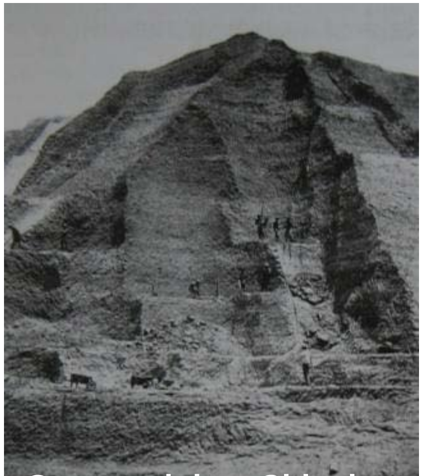
The Role of P as an Essential Nutrient for Animal Nutrition

- P is a major component of bones and teeth
- It is important for lactating animals
- P and calcium (Ca) are closely associated in animal nutrition
- It is essential for energy transfer and utilization

History of Phosphate Fertilizer

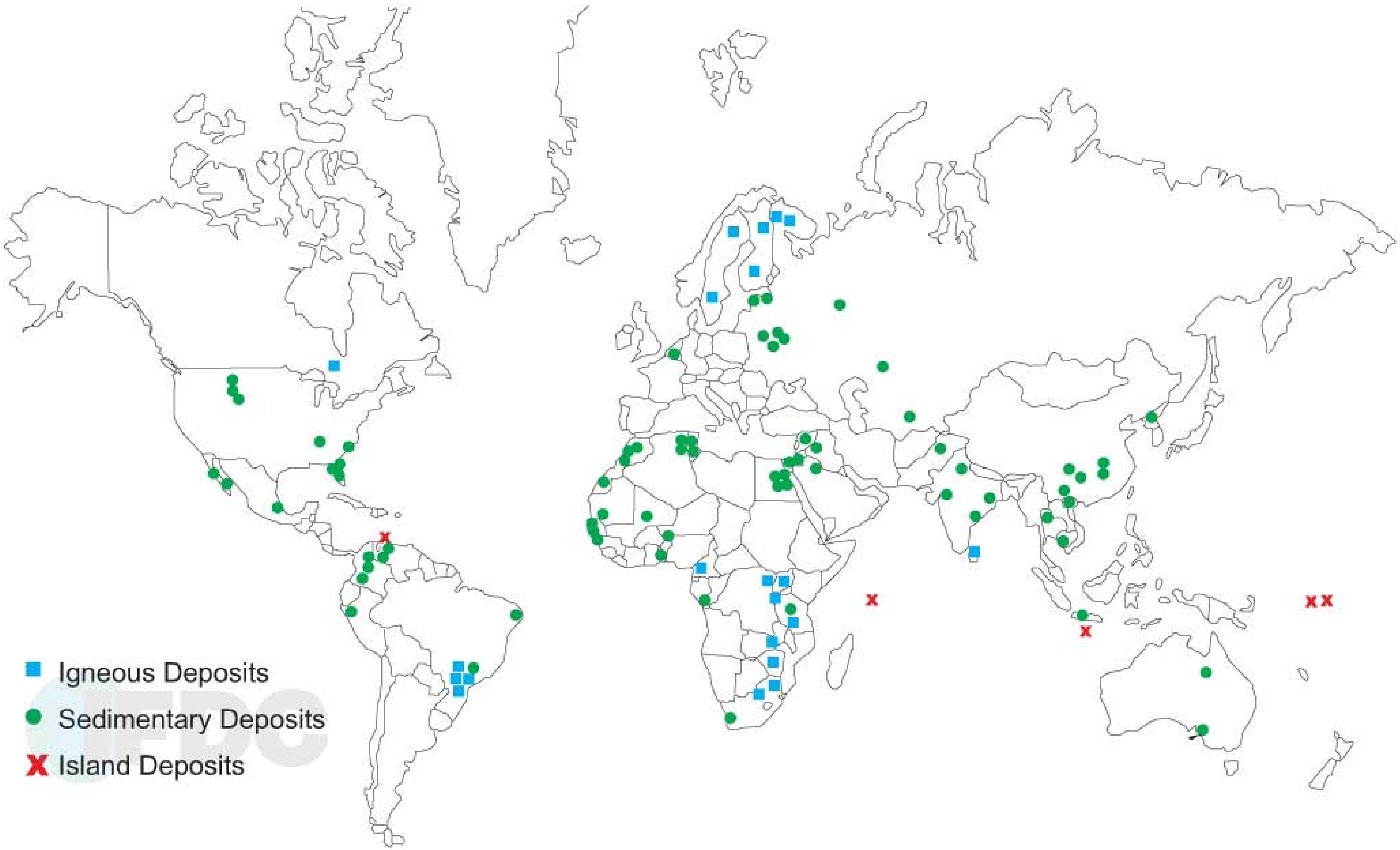
- Early sources were mostly animal based – bones, guano, manure
- Treatment of bones with acid to increase P solubility started early to mid 1800s
- Sulfuric acid treatment process of bones and P minerals (apatite) was patented in mid 1800s.
- Today most P fertilizer production is based on acidification of apatite from phosphate rock (PR)



Guano mining, Chincha Islands, Peru 1860

U.S. phosphate operation, late 1800s

Map of World P Resources



Source: IFDC

Phosphate Rock Reserves and Resources

- PR is a finite natural resource
- *Reserves* are generally defined as materials that can be economically produced at the present time using existing technology
- *Resources* include reserves and any other materials of interest that are not reserves
- Some have predicted that we are nearing "peak production" and that a scarcity of PR is looming
- An exhaustive review (IFDC, 2010) provides more details on global P reserves

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PR Reserves and Resources

- Recent review by IFDC shows much larger world reserves than formerly estimated
- This table shows top five countries in order of reserve holdings based on IFDC estimates
- Based on this information, the world will not soon run out of PR

Country	Mine production		USGS, 2010 est. reserves	IFDC est. reserves[1] (product)	IFDC est. resources[2]
	2008	2009			
	-mmt-				
Morocco	25.0	24.0	5,700	51,000	170,000
China	50.7	55.0	3,700	3,700	16,800
United States	30.2	27.2	1,100	1,800	49,000
Jordan	6.3	6.0	1,500	900	1,800
Russia	10.4	9.0	200	500	4,300
Other countries	38.5	35.8	3,427	2,007	45,580
World total (rounded)	**161**	**158**	**16,000**	**60,000**	**290,000**
Estimated longevity in years based on 2008-09 average production level			100	376	

[1]Reserves as usable or marketable product.
[2]Resources as unprocessed PR of varying grades or concentrate.

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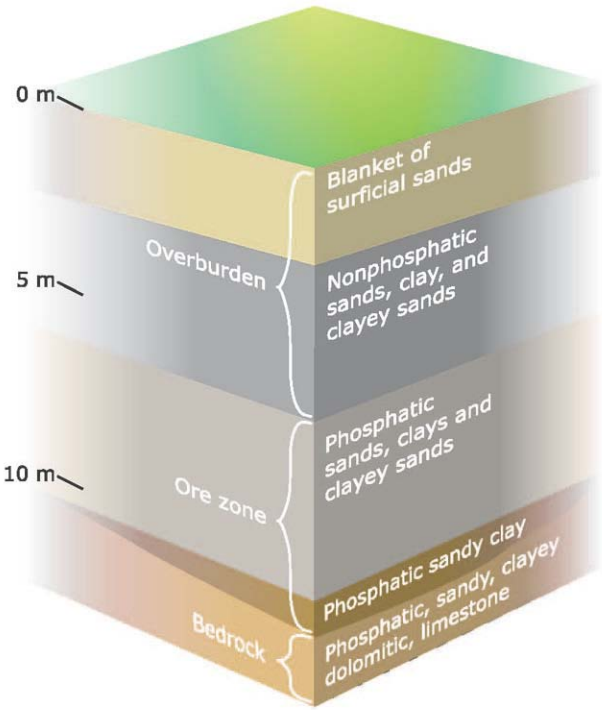
Formation of Phosphate Rock Deposits

- Most (>80%) PR used in fertilizer production is sedimentary, but igneous deposits are also used
- Sedimentary PRs were formed in continental shelf marine environments, and are thus taken from present or former continental margins
- Igneous PR was formed mostly in shield areas and rift zones

Generalized sedimentary deposit (Florida)



PR Mining Techniques

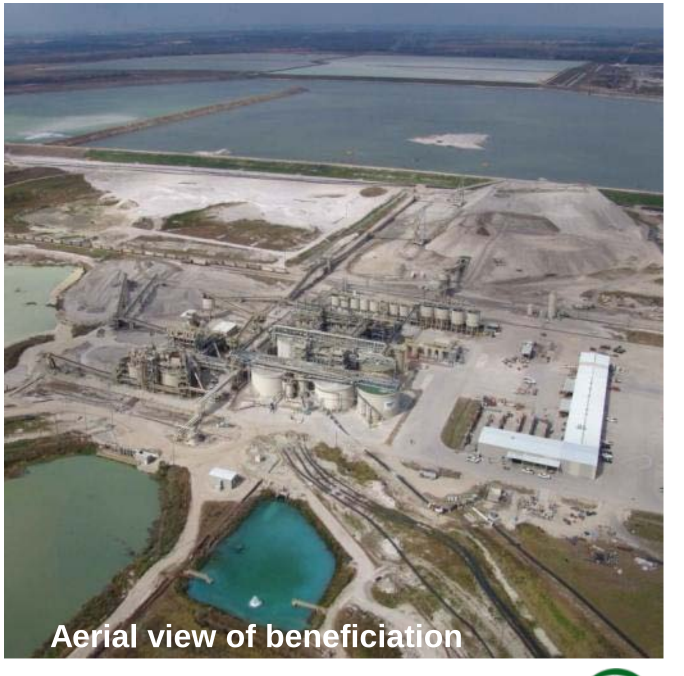
- Most phosphate rock is extracted through open pit mining techniques such as
  - Draglines
  - Bucket wheel excavators
  - Front end loader removal

Phosphate Rock Utilization Factors

- Concentrated (beneficiated) PRs are usually about 27% to 37% P_2O_5 (may be as low as ~23%)
- Low free carbonate content to avoid excess consumption of acid in phosphoric acid production
- Low Fe_2O_3, Al_2O_3, and MgO contents (below ~5%) to avoid formation of intermediate products
- Low Cl^- content (<500 ppm) to prevent equipment corrosion

Ore Impurities and Beneficiation

- Initial removal of impurities from PR ore is called beneficiation
- Beneficiation of PR involves removal of materials such as sand, clay, carbonates, organics, and iron oxide
- Beneficiation may involve
  - Screening (wet or dry)
  - Washing
  - Hydrocyclones
  - Calcination
  - Flotation
  - Magnets


Aerial view of beneficiation

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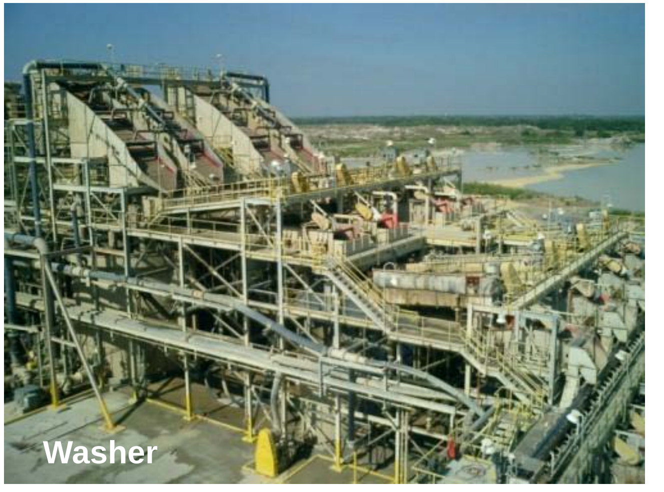
Ore Washing and Screening

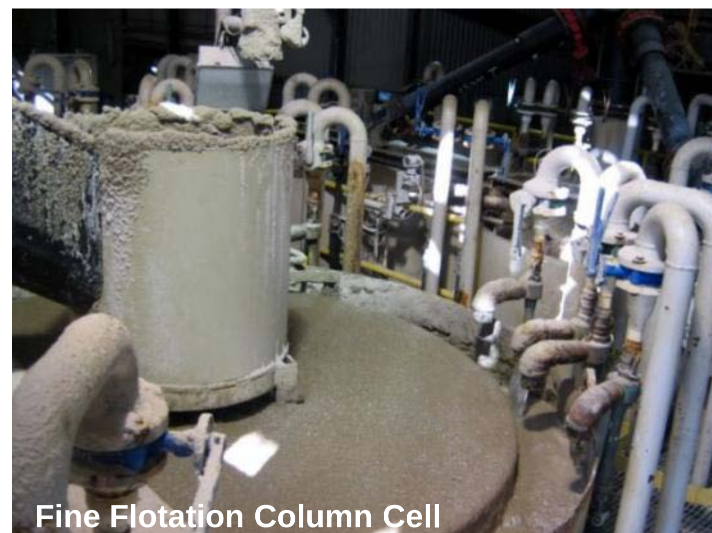
- Separates oversize material (3 to 20 cm)
- Removes clays and other fines which result in a slurry of suspended waste called “slime”
- In areas without sufficient water, dry screening may be used



Ore Flotation

- Froth flotation requires deslimed feedstock
- The first step involves bubbling air through an anionic collector such as fatty acid
- Fine ore is passed though flotation cells, PR is attracted to the anionic collector, and rises with froth
- Floating apatite is thus separated from silica tailings by overflow or paddlewheels


Conventional Fine Flotation Circuits


Fine Flotation Column Cell

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Ore Calcination

- Is used at some locations to remove organic matter
- Organic matter is burned by passing ore through furnace
- Results in higher quality product
- Used where energy cost, especially natural gas, is low

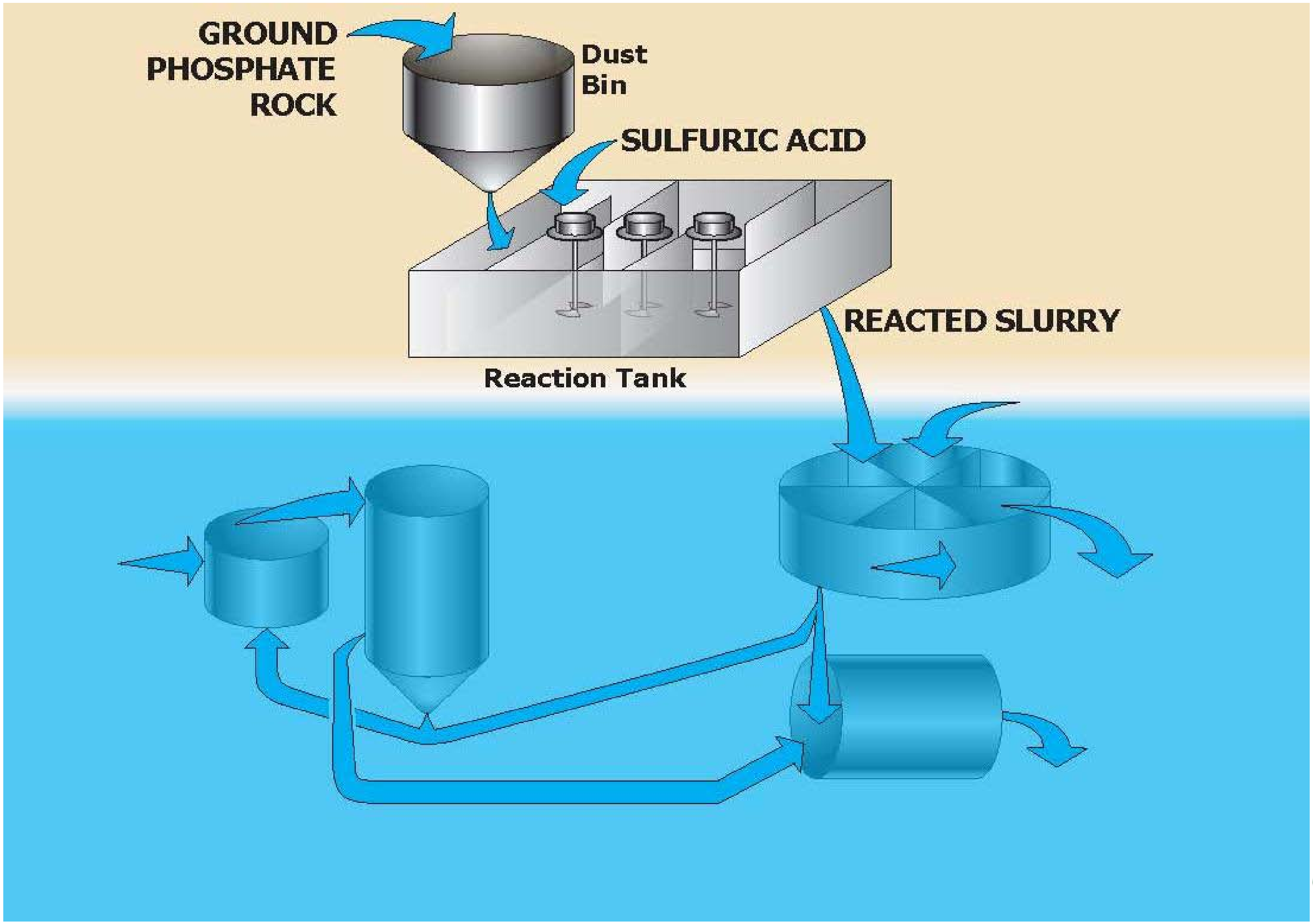

Non calcined PR, 67% BPL


Calcined PR, 72% BPL

Conversion of PR to Phosphoric Acid

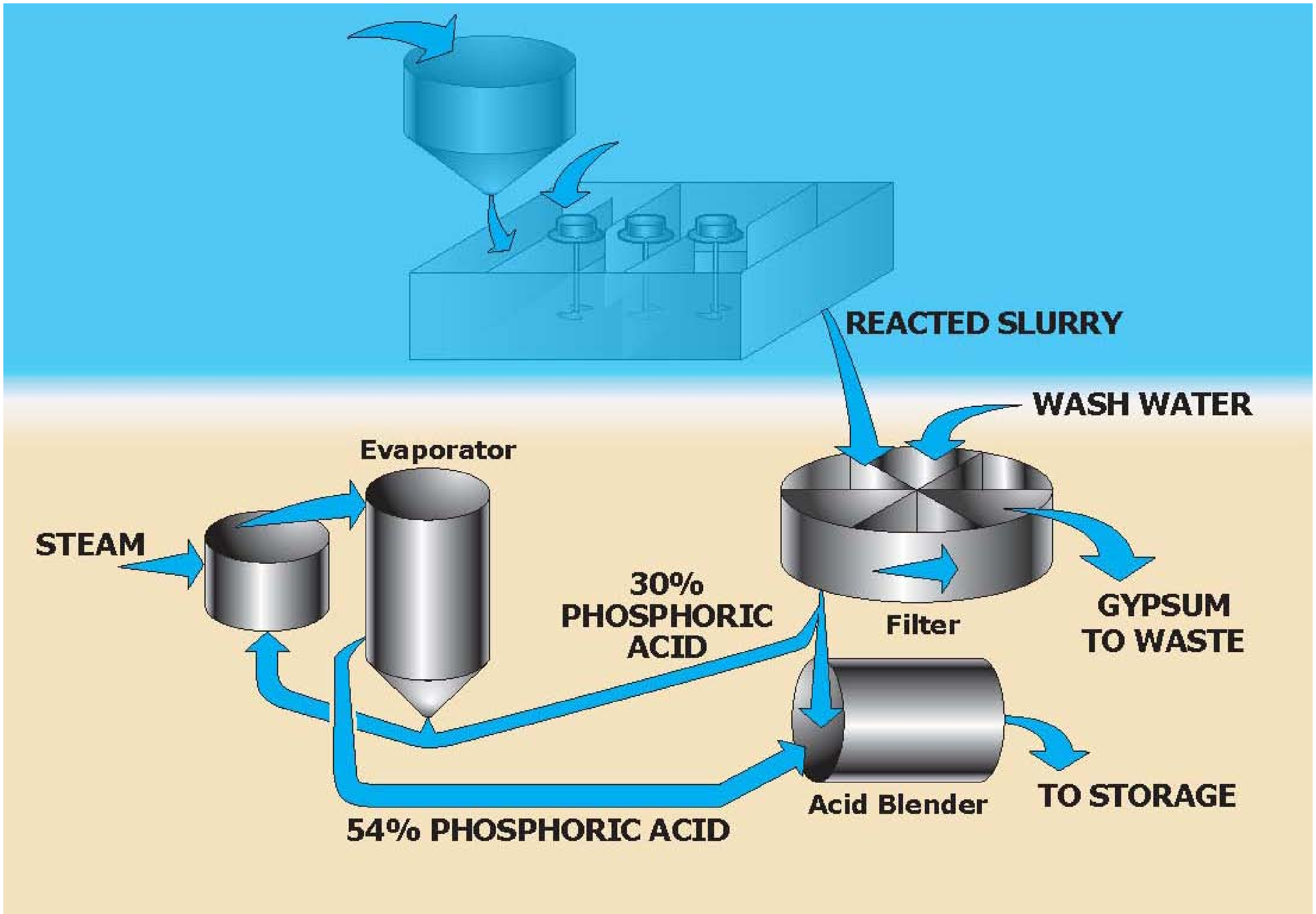
- After beneficiation, PR is converted to phosphoric acid
- Two processes of phosphoric acid production
  - Wet (chemical) process
  - Electric furnace (thermal) process
- The majority of P fertilizer is produced by wet process
  - Reaction of PR with acid
- The most common acid used on wet process is sulfuric (although others such as nitric acid are also used)
- The two major feedstocks in P fertilizer manufacturing are PR and elemental S

Wet Process Phosphoric Acid Production



(Cont.)

Wet Process Phosphoric Acid Production



Tailing Disposal

- Two major tailings produced in P fertilizer manufacture
  - Slime
  - Phosphogypsum
- Slime is produced by the separation of clay and other “fines” from PR
- Slime may be
  - placed in settling ponds
  - disposed of in the sea
  - placed in mined-out areas for reclamation

Tailing Disposal (Continued)

- Phosphogypsum (PG) is produced in the reaction of sulfuric acid with PR
- Most PG is placed in stacks near the point of production
- In some countries it is disposed of in the sea
- Only a small percentage (~15%) of PG is reused in
  - agricultural applications
  - cement retardant
  - construction materials
  - plaster board
- Where nitric acid is used to produce P fertilizer there is no gypsum byproduct


Gypsum stack

Mine Land Reclamation

- Mineland is reclaimed after ore is removed
- Reclaimed land can be more productive than in the original state
- Revegetation and reestablishment of ecosystem and wildlife habitat are of utmost importance in reclamation efforts

P Fertilizer Sources – Dry Granular

- Ordinary or normal superphosphate (OSP or SSP)
  - $Ca\ (H_2PO_4)_2 \cdot H_2O$
  - Low analysis (0-20-0-10S)
  - Simple to produce– results from reaction of PR with sulfuric acid
  - Oldest source – less popular than in the past
- Triple superphosphate (TSP)
  - First high analysis P fertilizer (0-46-0)
  - Results from reaction of PR with phosphoric acid
  - Production has declined since the 1980s in favor of ammoniated phosphates

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P Fertilizer Sources – Dry Granular (Cont.)

- Diammonium phosphate (DAP)
  - Analysis, 18-46-0
  - Produced by reacting 2 moles ammonia with 1 mole of phosphoric acid
  - Worlds major dry P fertilizer
- Monoammonium phosphate (MAP)
  - Typical analysis, 11-52-0
  - Produced by reacting 1 mole ammonia with 1 mole of phosphoric acid
  - Lower quality PR can be used in production of MAP than DAP

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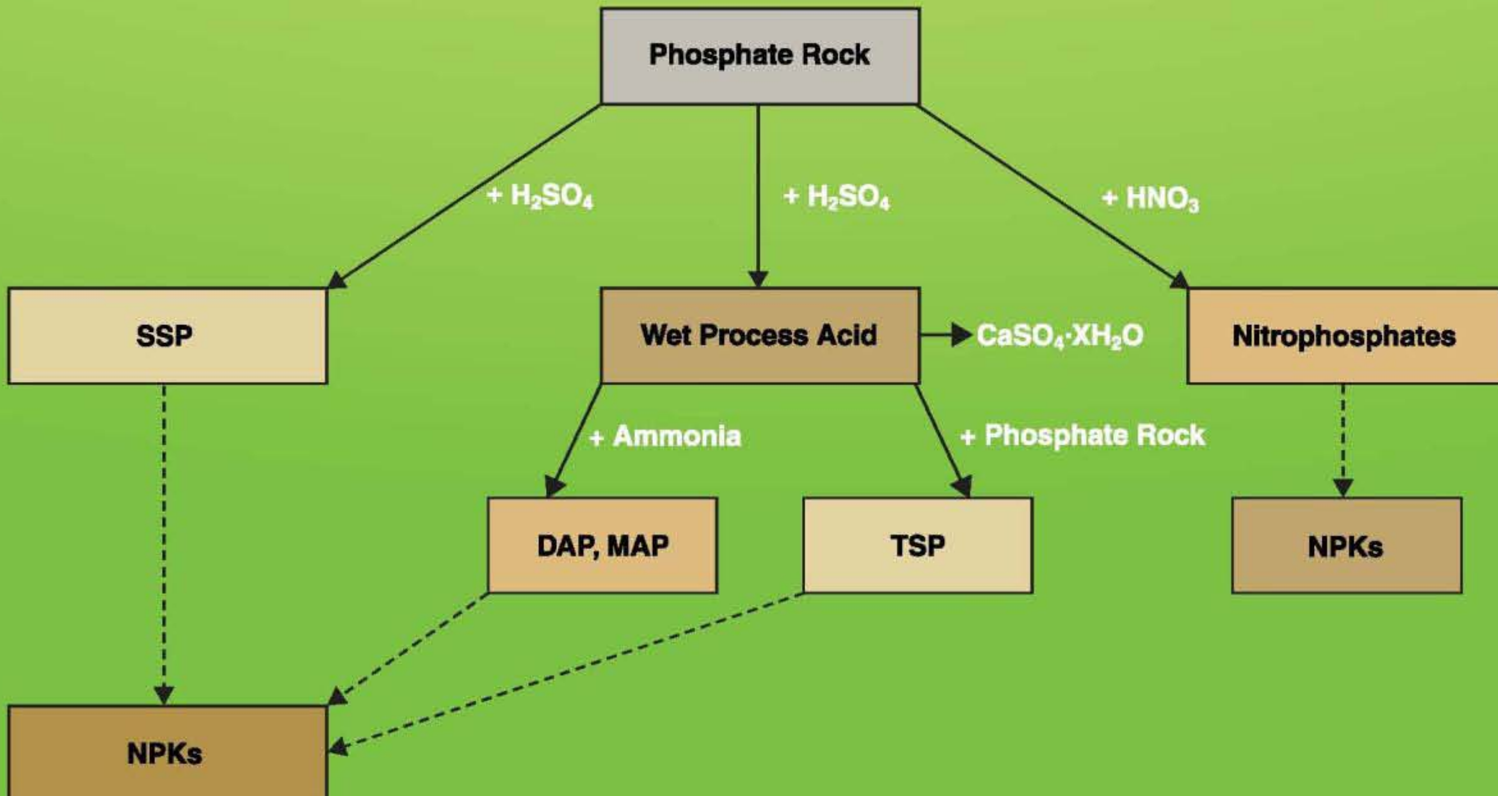
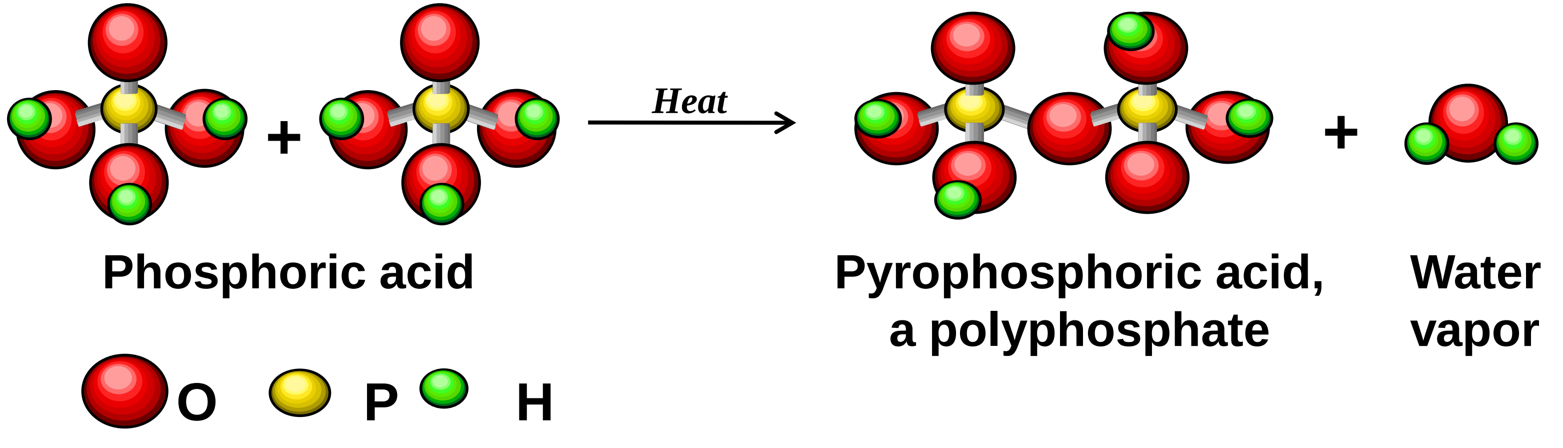
P Fertilizer Sources – Dry Granular

- Simplified flowchart of granular P production



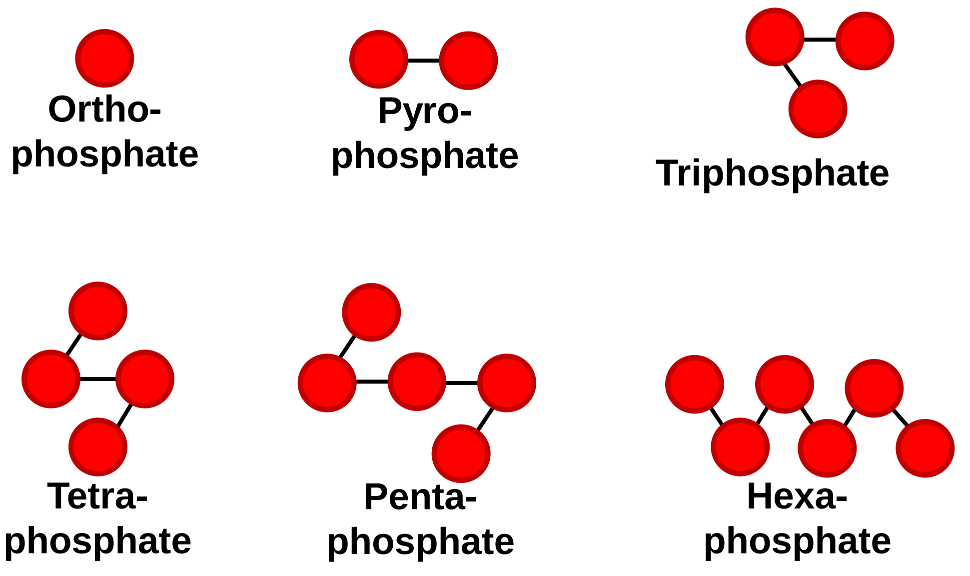
P Fertilizer Sources – Fluid

- Superphosphoric acid
  - Used as feedstock in the production of liquid polyphosphate fertilizers
  - Produced by dehydration of phosphoric acid
  - Contains 68 to 70% P_2O_5
  - Consists of mix of poly (20 to 35%) and orthophosphate



P Fertilizer Sources – Fluid (Cont.)

- Polyphosphates
  - Consist of a variety of polymers
  - Major polymer is pyrophosphate (two P molecules linked), but longer chained polyphosphates are also present



P Fertilizer Sources – Fluid (Cont.)

- Ammonium polyphosphate (APP)
  - Analysis 10-34-0 or 11-37-0
  - Major liquid P source
  - Mostly produced in TVA pipe reactor, introduced in 1972
  - Produced by reaction of superphosphoric acid, ammonia, and water
  - 70 to 75% of P is polyphosphate, the remainder is orthophosphate
  - Has good sequestering ability and storage characteristics

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P Fertilizer Sources – Fluid (Cont.)

- Suspensions
  - First introduced in the 1960s
  - Consist of crystals suspended by gelled clay
  - Analysis intermediate between solutions (polyphosphate) and granular
  - Base materials commonly include anhydrous ammonia, MAP, water, attapulgite clay, and potash (KCl)
  - Distressed products can often be used to produce suspensions
  - Storage and application characteristics are poor relative to polyphosphates, thus they often require more management

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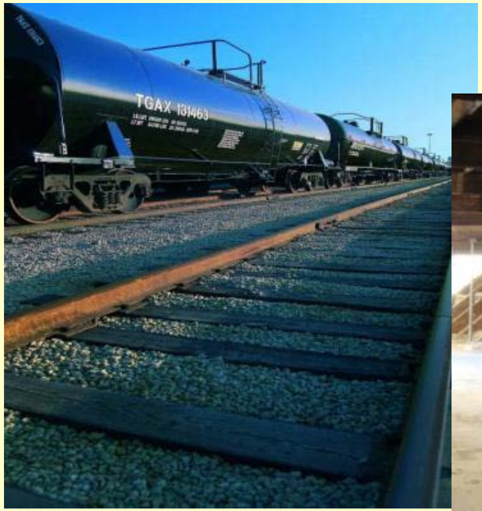
Shipping and Storage



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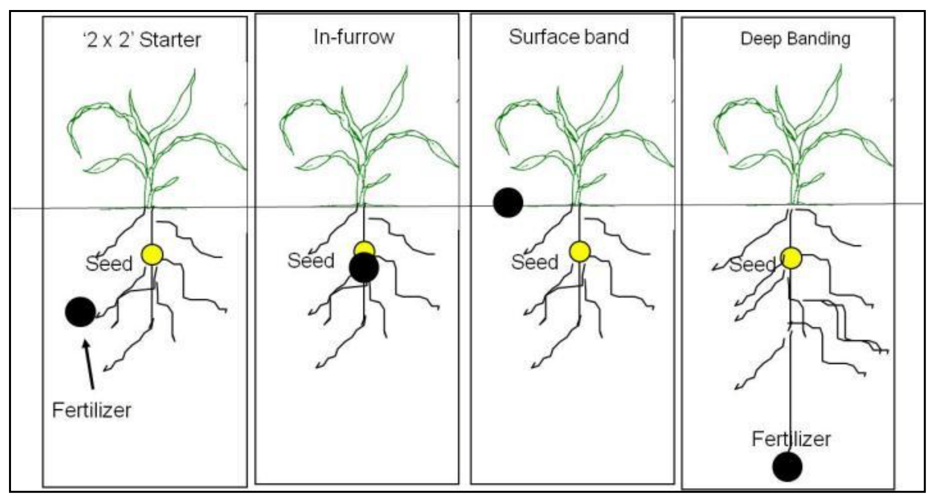
Phosphorus Fertilizer and the Soil

- Common commercial P fertilizers are highly (≥90%) water soluble
- Once dissolved in soils, orthophosphate is available for plant uptake
- Polyphosphates in APP must be converted to orthophosphate for plant uptake.
- Conversion or hydrolysis of poly to ortho in soils happens readily and does not affect nutritional value
- P chemistry in soils is complex – P may become sparingly available to plants in some soils due to formation of less soluble products

Phosphorus Fertilizer Placement

- P fertilizer may be broadcast on the soil surface (liquid or dry) or it can be placed in a concentrated band
- There may be advantages to banding, including
  - Early crop growth enhancement
  - Concentration of P to minimize soil contact and reaction
  - Placement in the root zone



P Fertigation

- P fertilizer is sometimes applied with irrigation water, although not as commonly as N
- P fertigation requires special consideration of fertilizer properties and water chemistry
- It can cause system plugging and fouling by reacting with
  - Calcium
  - Magnesium
  - Ammonium
  - Iron
- Successful P fertigation requires careful planning!

High Yielding Crops Remove Large Amounts of P

Nutrients removed in crop harvest, including P, must eventually be replaced or production will suffer

Crop	Yield/A	Nutrient removal, lb P_2O_5/A	Yield, mt/ha	Nutrient removal, kg P_2O_5/ha
Maize	180 bu	80	11	90
Wheat	60 bu	30	4	34
Rice	70 cwt	45	7.8	50
Cotton	3 bales	35	1.6	39
Alfalfa	8 tons	120	18	134
Potato	500 cwt	75	56	84

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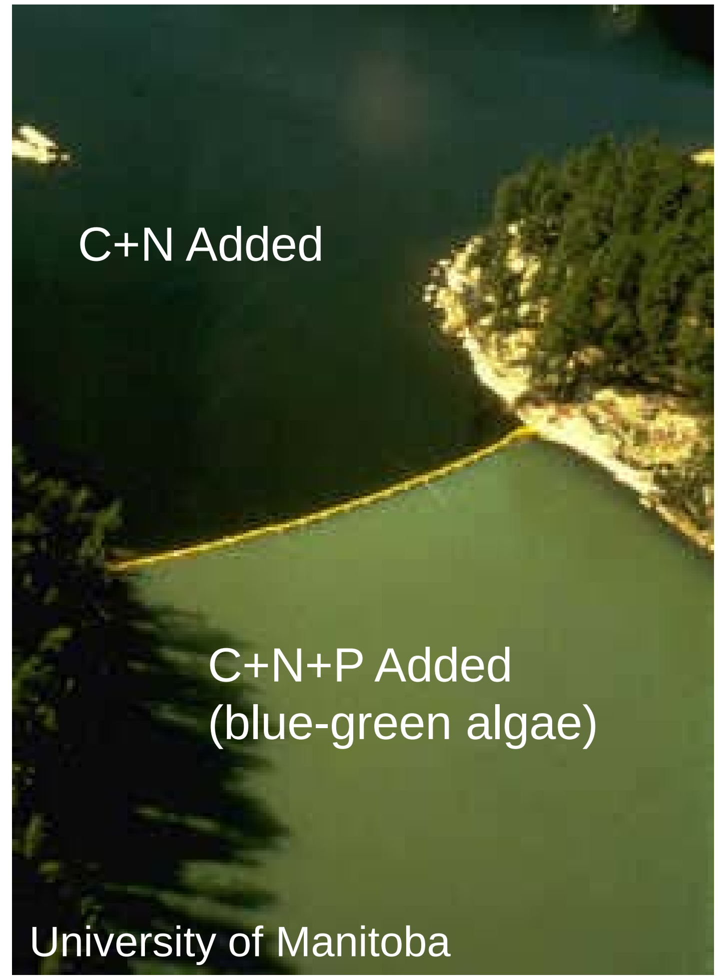
Phosphorus and the Environment

- Eutrophication – the natural aging of lakes or streams by nutrient enrichment
- Nutrient additions can accelerate the process
- P is often the limiting element
- Dissolved oxygen is depleted by excessive plant growth
- Best management practices (BMPs) can help minimize P runoff from fields



Summary

- Phosphorus is essential for healthy plants and animals
- Most P fertilizer comes from reacting PR with sulfuric, phosphoric or nitric acid
- Many excellent granular, liquid, and suspension P fertilizers are available for specific needs
- Addressing the need for P fertilizer is part of a complete and balanced crop nutrition program
- BMPs help ensure minimal environmental impacts from P fertilizer

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