VI. PHOSPHORUS

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Outline

- 6.1 Introduction
- 6.2 Functions & Forms of P in Plants
- 6.3 P Cycles
- 6.4 Soil P resources
- 6.5 Soil P availability
- 6.6 Agronomic role of P
- 6.7 P Management

6.1 INTRODUCTION

- Phosphorus is macro nutrient (essential and required in high amount)
- Phosphorus in soil as limiting factor for high crop productivity.
- P deficiency : in Andisol, soil developed from limestones, acid mineral soil. Why …?
- How to manage P?

6.1 INTRODUCTION

- Scr umum, P dalam tanah sering ketersediaannya rendah dan tidak mencukupi kebutuhan P untuk produksi tanaman yang tinggi.
- Akibatnya tanaman sering menunjukkan gejala defisiensi P
- Oki, utk produksi yang tinggi perlu pemupukan P
- Bgm pemupukan P yang efektif dan efisien, faktor-faktor apa saja yang mempengaruhi efektivitas dan efisiensi pemupukan P perlu diketahui dg baik.

6.2. FUNCTIONS & FORMS OF P IN PLANTS

Established date for essentiality/researchers:

- 1839 (Liebig) and 1861 (Ville)

Functions in plants:

- A component of certain enzymes and proteins, adenosine triphosphate (ATP), ribonucleic acids (RNA), deoxyribonucleic acids (DNA), and phytin.
- ATP is involved in various energy transfer reactions, and RNA and DNA are components of genetic information.

Content and distribution in plants:

- Consists of 0.15% to 1.00% of the dry weight of most plants with sufficiency values from 0.20% to 0.40% in recently mature leaf tissue.
- Critical values for P are normally less than 0.20% (when deficient) and greater than 1.00% (when in excess).
- See pages 136–137 for a listing of critical values and sufficiency ranges for a number of crop plants.
- Content in leaves tends to decrease with age.
- Highest concentration found in new leaves and their petioles.
- High-yielding crops contain from 15 to 75 lbs P/A (17 to 84 kg P/ha).
- Amount of P present when crops are harvested will be considerably less for grain crops when only the grain is removed, leaving behind most of the P in the remainder of the plant.
- Soluble P (in 2% acetic acid) present as the orthophosphate (PO_4^{3-}) anion in main stems and leaf petioles of the actively growing portions of the plant, ranges from 100 to 5,000 ppm of the dry weight and can be used to evaluate the P status of the plant; critical concentrations occur at approximately 2,500 ppm.

TABLE 3.1
Diagnostic Ranges for Phosphorus Concentrations in Crop and Ornamental Plants

A. Field Crops

Species	Growth Stage	Plant Part	Deficient	Low	Sufficient	High	Reference
Barley	GS 2	WP	<0.30				130
(*Hordeum*	GS 6	WP	<0.30	0.30–0.40	>4.0		130
vulgare L.)	GS 9	WP	<0.15	0.15–0.20	>0.20		130
	GS 10.1	WP	<0.15	0.15–0.20	0.20–0.50	>0.5	131
Cassava (*Manihot esculentum* Crantz)	Veg.	YML	<0.20	0.40	0.30–0.50		132
Chickpea (*Cicer*	45 DAP	WP	0.09–0.25		0.29–0.33		133
arietinum L.)	77 DAP	WP	0.15–0.20		>0.26		133
Dent corn (*Zea*	<30 cm tall	WP			0.30–0.50		134
mays var.	40–60 cm tall	WP		0.22–0.26			135
indentata	Tassel	Ear L		0.25			136
L.H. Bailey)	Silking	Ear L		0.28–0.32			137
	Silking	Ear L	<0.20		>0.29		138
	Silking	Ear L	0.22–0.32		0.27–0.62		139
	Silking	6th L from base		<0.32			140
	Silking	6th L from base	<0.21	<0.30	<0.33		141
	Silking	Ear L	0.16–0.24		0.25–0.40	0.41–0.50	142
	Silking	Ear L			0.25–0.40		143
	Silking	Ear L			0.22–0.23		135
	Silking	Ear L			0.26–0.35		144
	Silking	Ear L		0.27			145
Cotton	<1st Fl	YML			0.30–0.50		134
(*Gossypium*	July–August	L			0.30–0.64		146
hirsutum L.)	Early fruit	YML		0.31			147
	Late fruit	YML		0.33			147
	Late Mat	YML		0.24			147
	1st Fl	PYML PO_4-P		0.15		0.20	148
	Peak Fl	PYML PO_4-P		0.12		0.15	148
	1st bolls open	PYML PO_4-P		0.10		0.12	148
	Mat	PYML PO_4-P		0.08		0.10	148
Cowpea (*Vigna*	56 DAP	WP			0.28		149
unguiculata	30 cm	WP	0.28		0.27–0.35		150
Walp.)	Early Fl	WP	0.19–0.24		0.23–0.30		150
Faba or field bean (*Vicia faba* L.)	Fl	L 3rd node from A			0.32–0.41		151
Field pea	36 DAS	WP	<0.06		>0.92		152
(*Pisum*	51 DAS	WP	<0.53		>0.71		152
sativum L.)	66 DAS	WP	<0.46		>0.64		152
	81 DAS	WP	<0.40		>0.55		152
	96 DAS	WP	<0.43		>0.60		152

Continued

TABLE 3.1 *(Continued)*

Species	Growth Stage	Plant Part	Deficient	Low	Sufficient	High	Reference
	8–9 nodes	L 3rd node from A			0.36–0.51		151
	Pre-Fl	WP			0.16		153
Dry beans (*Phaseolus vulgaris* L.)	10% Fl	YML			0.40		154
	50–55 DAE	WP	0.22		0.33		155
Oats (*Avena sativa* L.)	GS 10.1	WP	<0.15	0.15–0.19	0.20–0.50	>0.50	131
	Pre-head	Upper L			0.20–0.40		134
Peanuts (*Arachis hypogaea* L.)	Early pegging	Upper L+S			0.20–0.35		156
	Pre Fl or Fl	YML			0.25–0.50		134
Pigeon pea (*Cajanus cajan* Huth.)	91 DAP	L	0.08		0.24		157
	30 DAP	L			0.35–0.38		158
	60 DAP	L			0.30–0.33		158
	90–100 DAP	L			0.19–0.28		158
	120–130 DAP	L			0.15–0.20		158
	160–165 DAP	L			0.15–0.18		158
Rice (*Oryza sativa* L.)	25 DAS	WP	<0.70	0.70–0.80	0.80–0.86		159
	50DAS	WP	<0.18	0.18–0.26	0.26–0.40		159
	75 DAS	WP	<0.26	0.26–0.36	0.36–0.48		159
	35 DAS	WP		0.25			160
	Mid till	Y blade			0.14–0.27		131
	Pan init	Y blade			0.18–0.29		131
PO_4-P	Mid till	Y blade		0.1	0.1–0.18		161
PO_4-P	Max till	Y blade		0.08	0.1–0.18		161
PO_4-P	Pan init	Y blade		0.08	0.1–0.18		161
PO_4-P	Flagleaf	Y blade		0.1	0.08–0.18		161
Sorghum (*Sorghum bicolor* Moench.)	23–29 DAP	WP	<0.25	0.25–0.30	0.30–0.60	>0.60	162
	37–56 DAP	YML	<0.13	0.13–0.25	0.20–0.60		162
	66–70 DAP (Bloom)	3L below head	<0.18	0.18–0.22	0.20–0.35	>0.35	162
	82–97 DAP (Dough)	3 L below head	<0.13	0.13–0.15	0.15–0.25	>0.25	162
	NS	YML			0.25–0.40		163
Soybean (*Glycine max* Merr.)	Pre-pod	YML			0.26–0.50		156
	Early pod	YML		0.35			136
	Early pod	YML			0.30–0.50		134
	Pod	Upper L		0.37			164
	August	L			0.25–0.60		165
Sugar beet (*Beta vulgaris* L.)	25 DAP	Cotyledon PO_4-P	0.02–0.15		0.16–1.30		166
	25 DAS	Oldest P PO_4-P	0.05–0.15		0.16–0.50		166
	25 DAS	Oldest L PO_4-P	0.05–0.32		0.35–1.40		166
	NS	PYML PO_4-P	0.15–0.075		0.075–0.40		167
	NS	YML PO_4-P	0.025–0.070		0.10–.80		167

TABLE 3.1 *(Continued)*

Species	Growth Stage	Plant Part	Deficient	Low	Sufficient	High	Reference
Sugarcane (*Saccharum officinarum* L.)	5 month ratoon	3rd LB below A		0.21			168
	4th mo.	3rd & 4th			0.24–0.30		
		LB below A			0.24–0.30		169
	3 mo.	Leaves	0.15–0.18		0.18–0.24	0.24–0.30	170
	Early rapid growth	Sheath 3–6	<0.05	0.08	0.05–0.20		171
Tobacco (*Nicotiana tabacum* L.)	Fl	YML			0.27–0.50		134
	Mat	L	0.12–0.17		0.22–0.40		172
Wheat (*Triticum aestivum* L.)	GS 3–5	WP			0.4–0.70		173
	GS 6–10	WP			0.2–0.40		173
	GS 10	Flag L			0.30–0.50		173
	GS 10	WP		030			136
	GS 10.1	WP	0.15–0.20		0.21–0.50	>0.50	131
	Pre-head	Upper LB			0.20–0.40		134
B. Forages and Pastures							
Alfalfa (*Medicago sativa* L.)	Early Fl	WP		<0.20			174
	Early Fl	WP		<0.30			174
	Early Fl	WP	<0.18		0.25–0.50		174
	Early Fl	WP	<0.20	0.21–0.22	0.23–0.30	>0.30	174
	Early Fl	WP		<0.25			174
	Early Fl	WP		<0.25			174
	Early Fl	WP		<0.25			174
	Early Fl	Top 15 cm	<0.20	0.20–0.25	0.26–0.70	>0.70	174
	Early Fl	Upper stem		0.35			174
	Early Fl	Midstem PO_4-P	<0.05	0.05–0.08	0.08–0.20	>0.20	174
Bermuda grass, Coastal (*Cynodon dactylon* Pers.)	4–5 weeks between clippings	WP	<0.16	0.18–0.24	0.24–0.30	>0.40	174
Bermuda grass, Common and Midland (*Cynodon dactylon* Pers.)	4–5 weeks between clippings	WP	<0.22	0.24–0.28	0.28–0.34	>0.40	174
Birdsfoot trefoil (*Lotus corniculatus* L.)	Growth	WP		<0.24			174
Clover, Bur (*Medicago hispida* Gaertn.)	Growth	WP			2.5		174
Clover, Ladino or White (*Trifolium repens* L.)	Growth	WP		<0.23			174
	Growth	WP		<0.30			174
	Growth	WP		0.10–0.20	0.30		174
	Growth	WP		<0.25	0.25–0.30		174

Continued

Interaction with other elements:

- Elemental ratio of 3-to-1 between N and P is considered critical.
- Relationships exist between P and Cu, Fe, Mn, and zinc (Zn), with a 200-to-1 ratio between P and Zn being critical.
- Ratio of N to P is used as a DRIS norm for interpreting a plant analysis (see Beverly, 1991).

Available forms for root absorption:

- Exists in most soils in about equal amounts of organic or inorganic forms.
- Dihydrogen phosphate ($H_2PO_4^-$) and monohydrogen phosphate (HPO_4^{2-}) are the two anion forms of P in the soil solution, which form and their concentration depending on soil water pH.
- Al, Fe, and Ca phosphates are the major inorganic sources of P, the relative amount among these three forms being a function of soil water pH.
- Release of P into the soil solution with the decomposition of crop residues and microorganisms can be a major source of P for plant utilization.
- Plant availability is influenced by soil water pH (see Figures 9.1 and 9.2).

P Cycles

- Input: soil P sources
- Output: Soil P loss
- Process: P behaviour in soil

6.3 P cycles

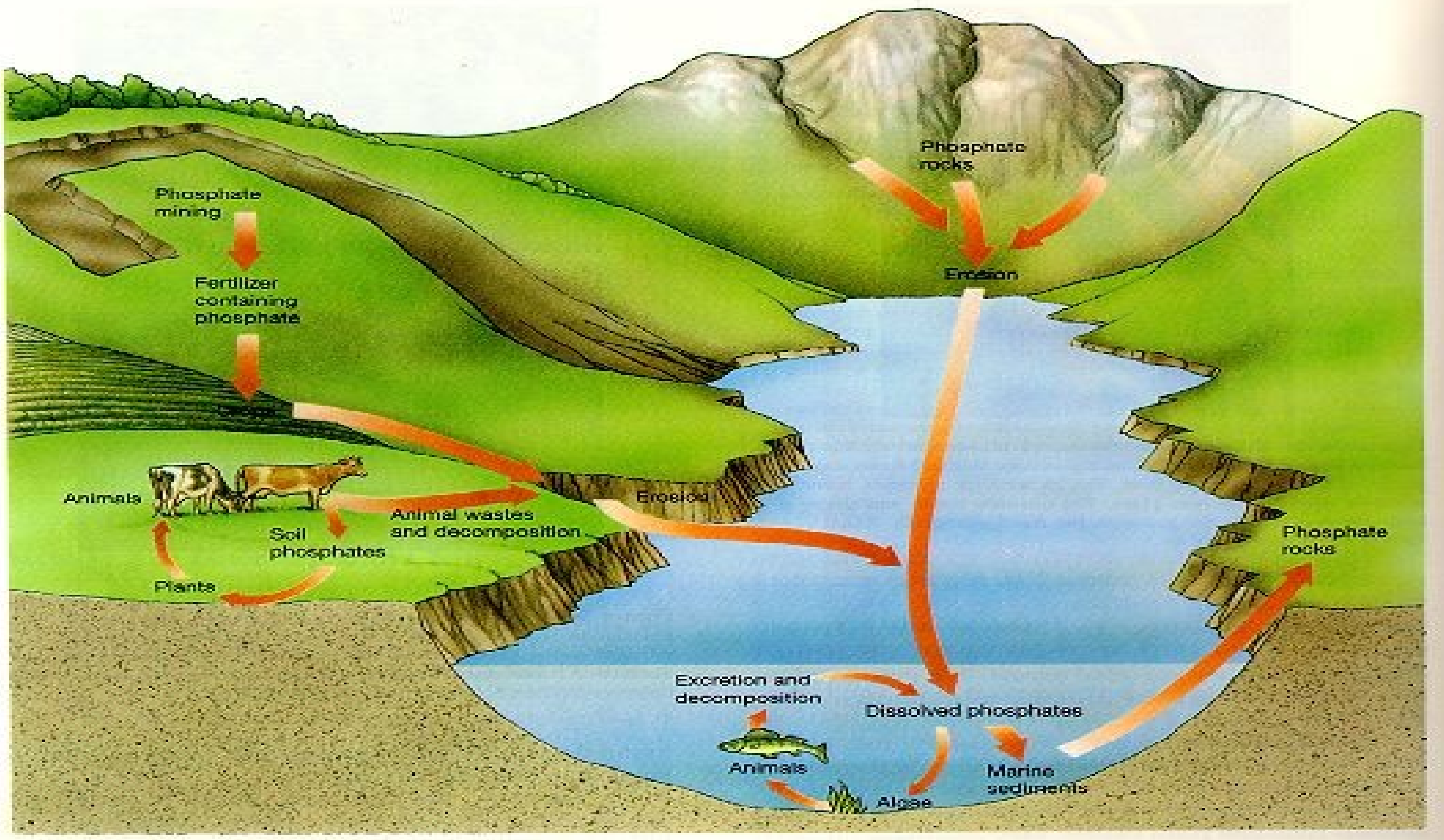
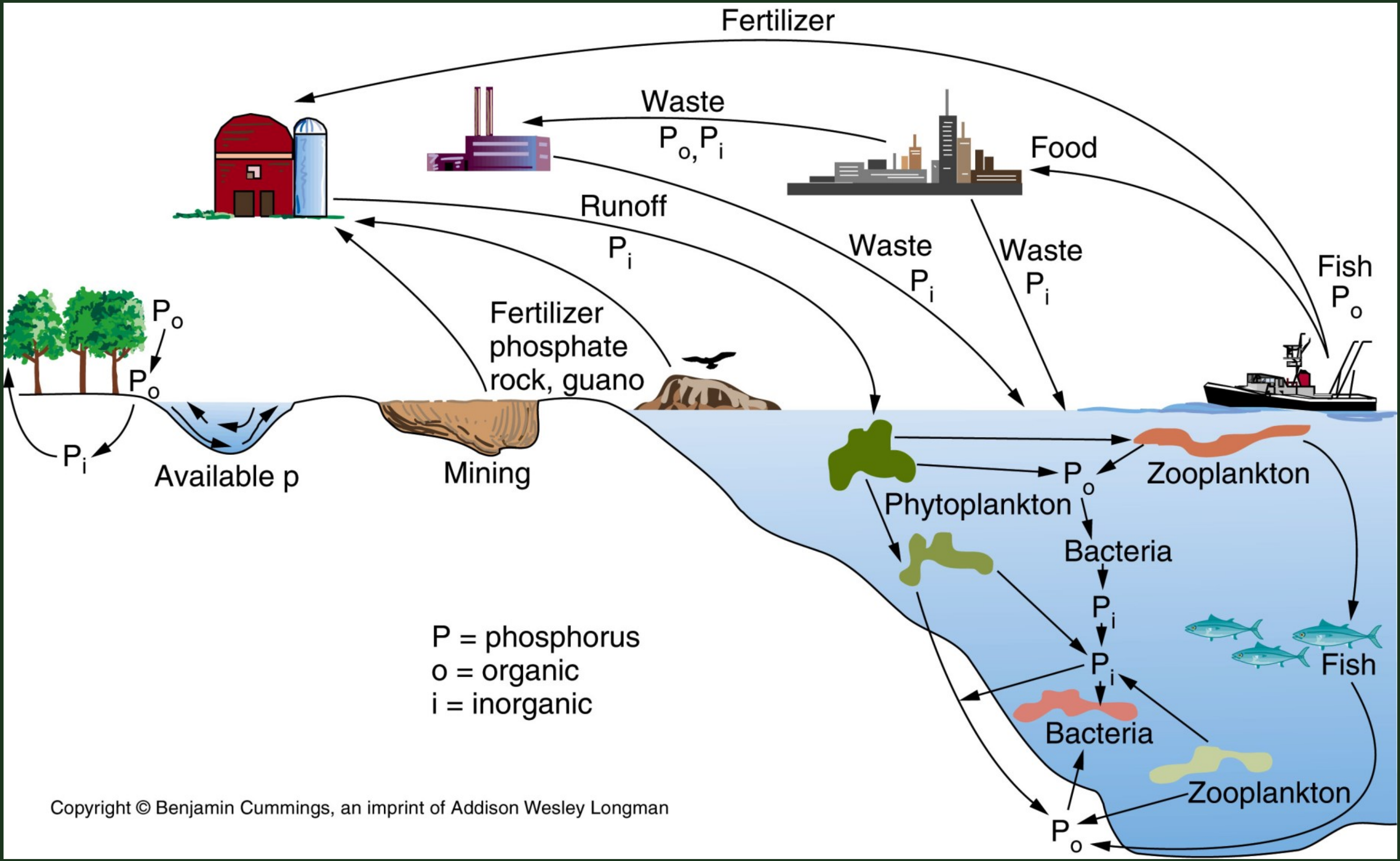
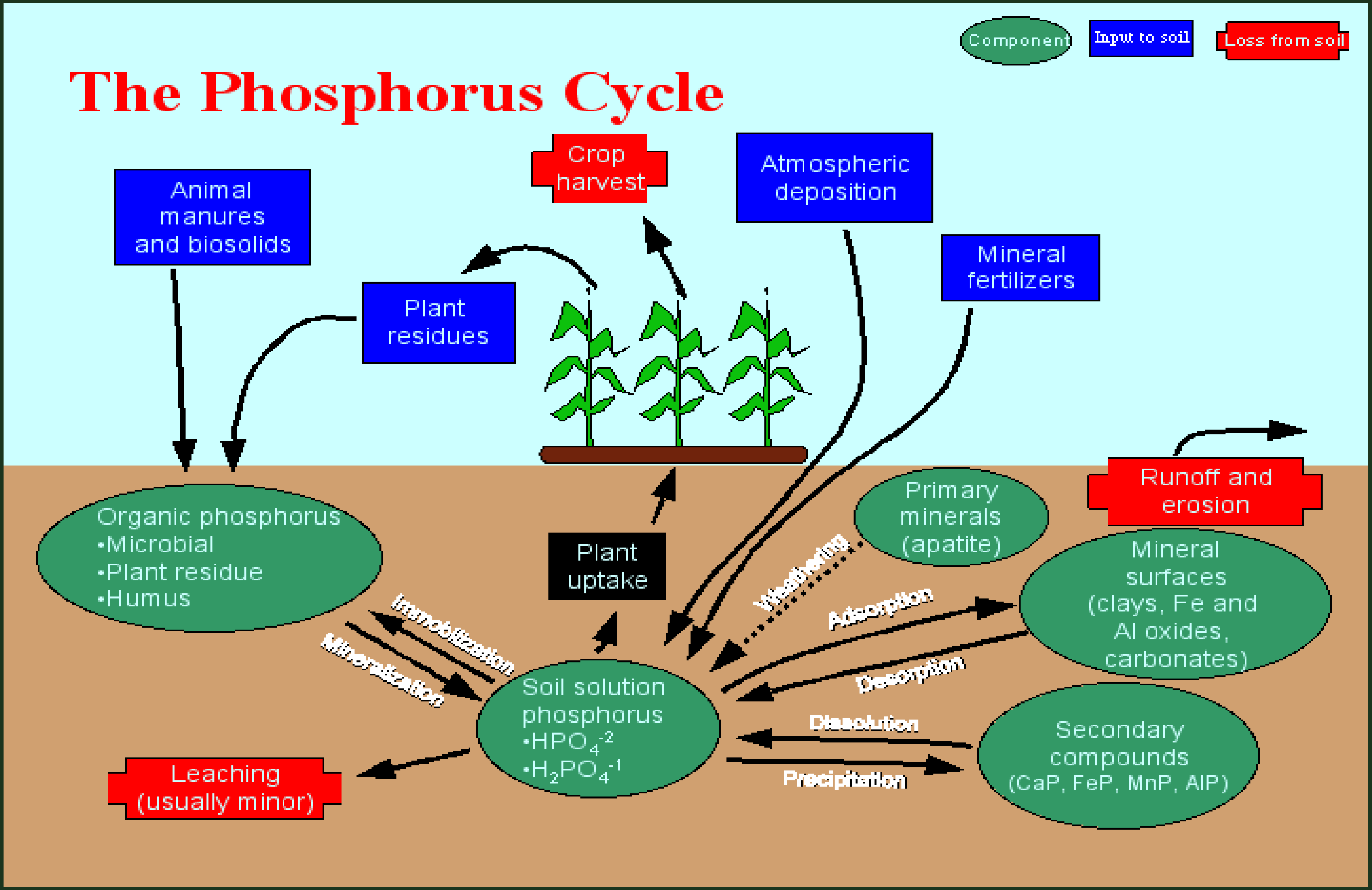


Figure 54–5 The phosphorus cycle in terrestrial and aquatic environments. Recycling of phosphorus (as phosphate, PO_4^{3-}) is slow because no biologically important form of phosphorus is gaseous. Phosphate that becomes part of marine sediments may take millions of years to solidify into rock, uplift as mountains, and erode again to become available to living things.

The phosphorus cycle in terrestrial and aquatic ecosystems.



6.3 P cycles



Component
Input to soil
Loss from soil
The Phosphorus Cycle
Crop harvest
Atmospheric deposition
Animal manures and biosolids
Mineral fertilizers
Plant residues
Runoff and erosion
Primary minerals (apatite)
Organic phosphorus
•Microbial
•Plant residue
•Humus
Plant uptake
Mineral surfaces (clays, Fe and Al oxides, carbonates)
Weathering
Adsorption
Immobilization
Mineralization
Desorption
Soil solution phosphorus
•HPO_4^{-2}
•$H_2PO_4^{-1}$
Dissolution
Secondary compounds (CaP, FeP, MnP, AlP)
Precipitation
Leaching (usually minor)

6.3 P cycles

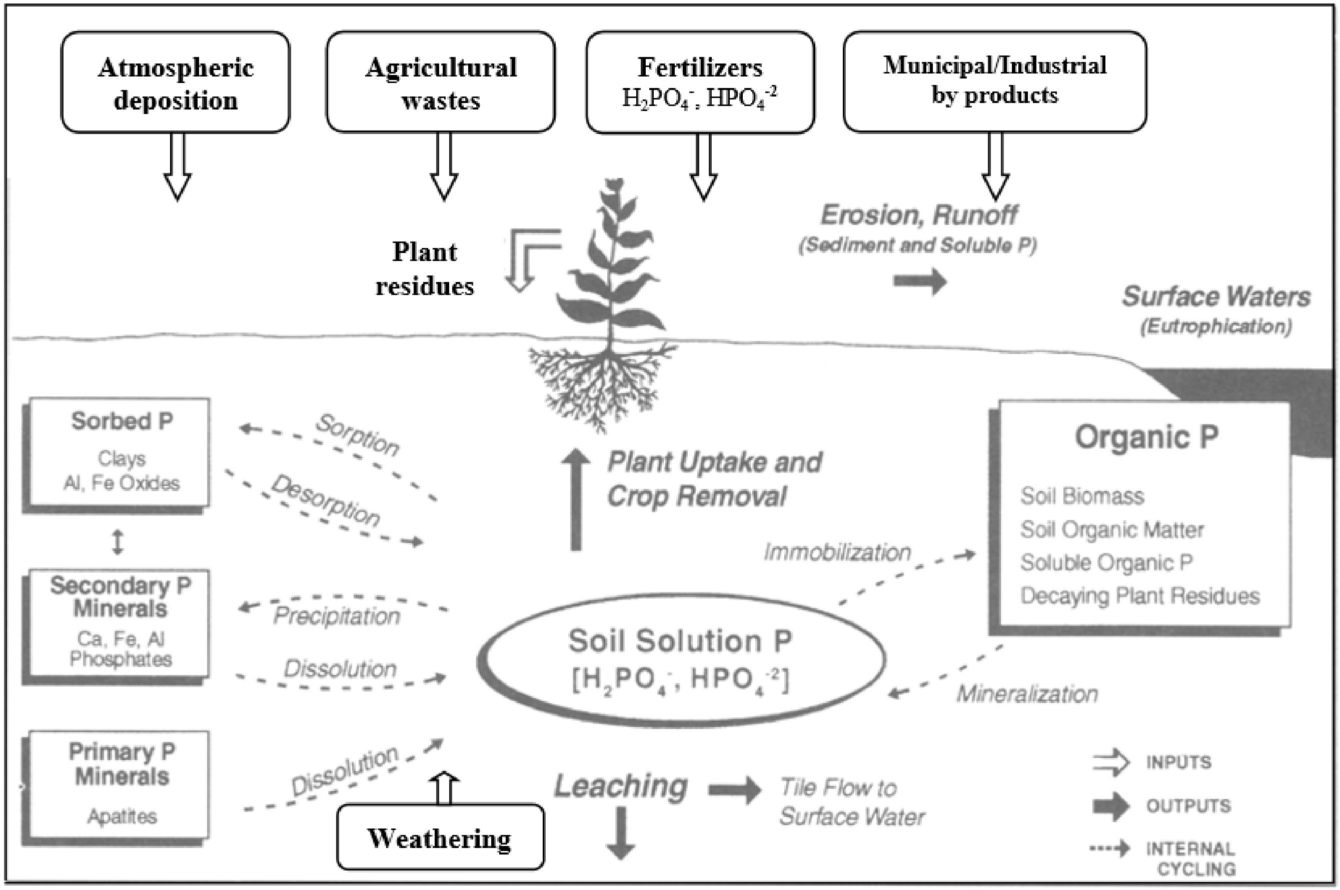


Figure 6. Phosphorus cycle in the soil with inputs, outputs and transformations that take place in the soil (modified from Pierzynski et al., 2000).

6.3 P cycles

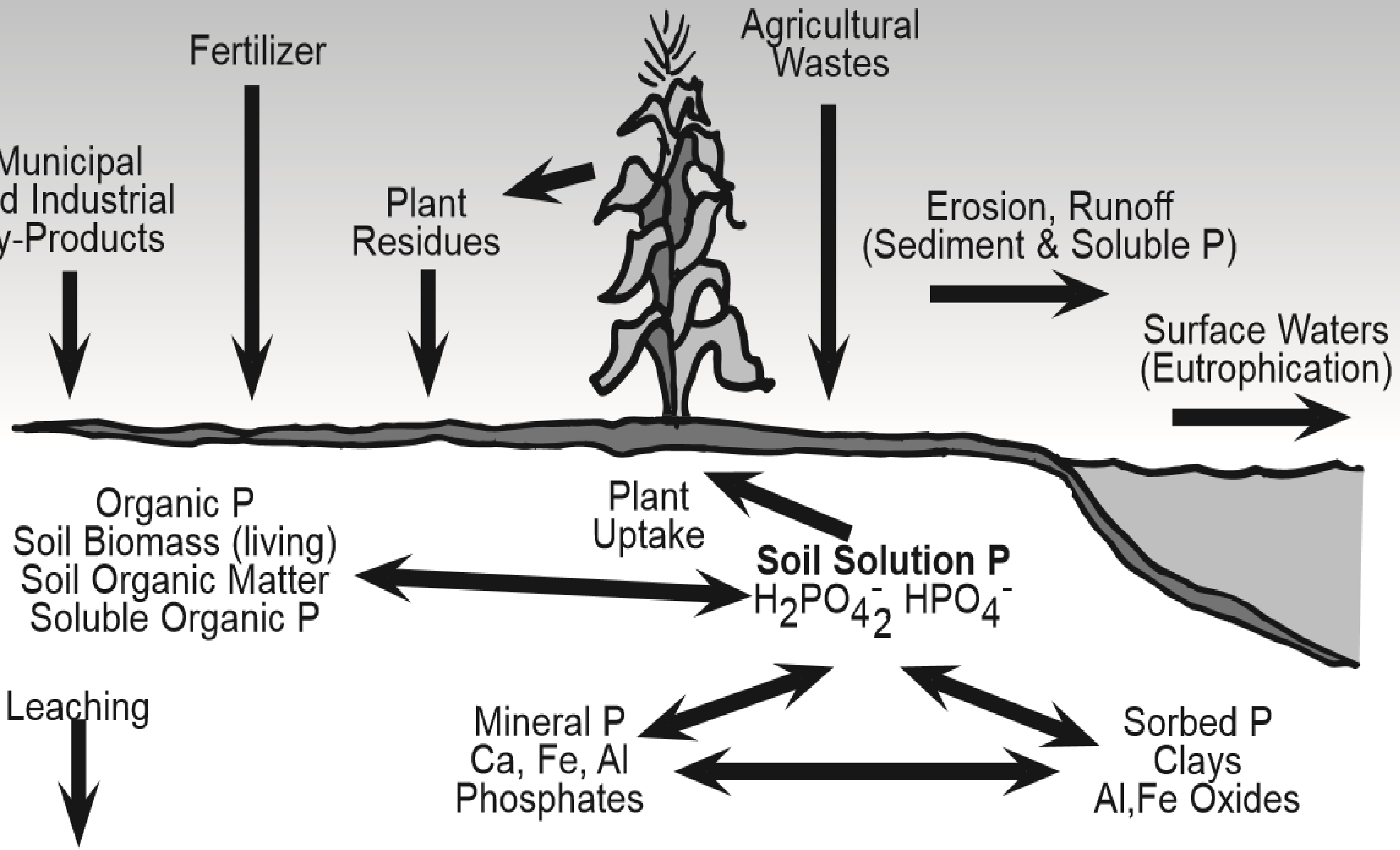


Fig. 3. The soil phosphorus cycle (adapted from Pierzynski et al., 1994)

6.3 P cycles

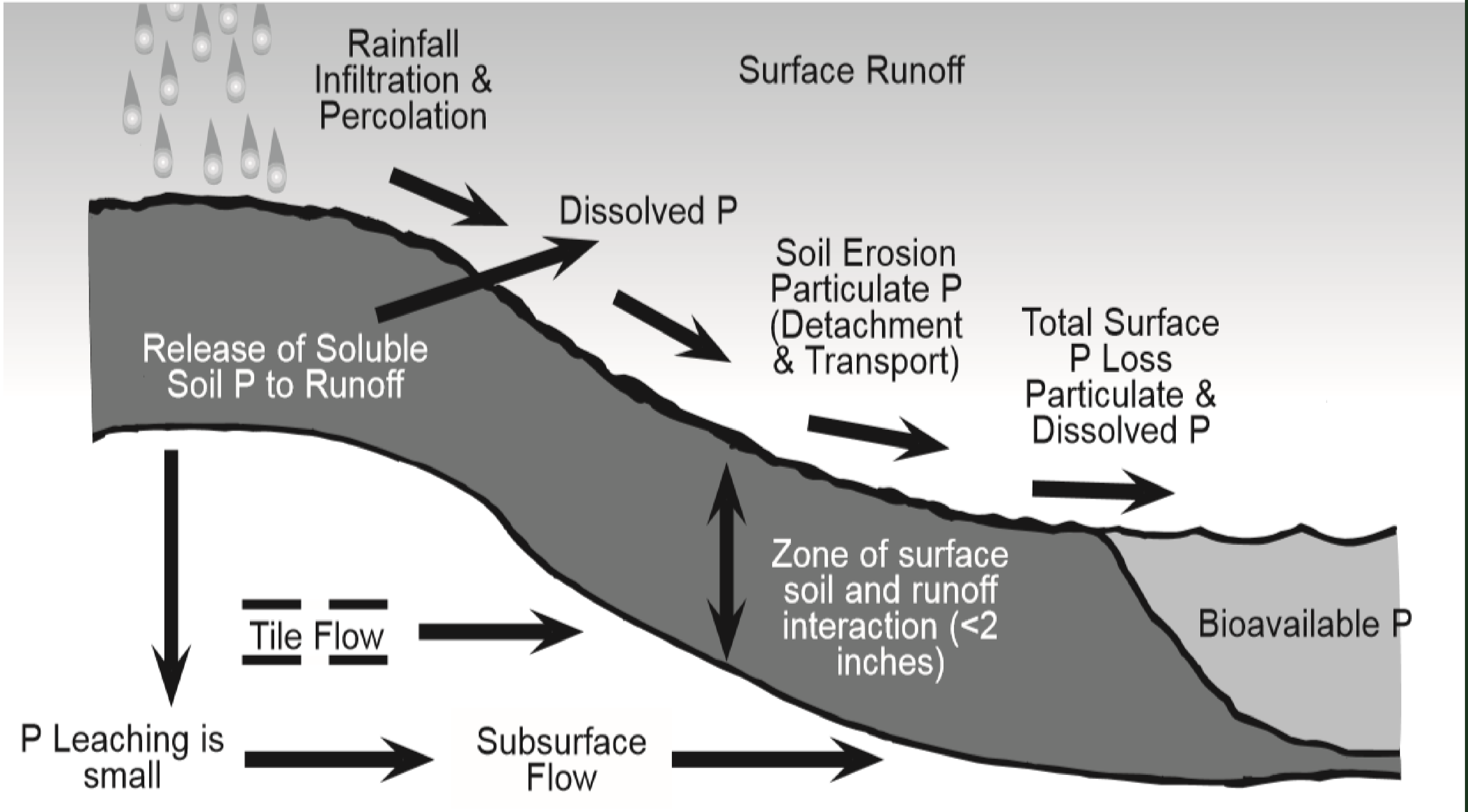


Fig. 4. Processes that are responsible for the transport of phosphorus from agricultural fields to surface water. In most soils, potential losses of phosphorus in surface runoff is much greater as compared to losses by leaching and subsurface flow.

6.3 P cycles

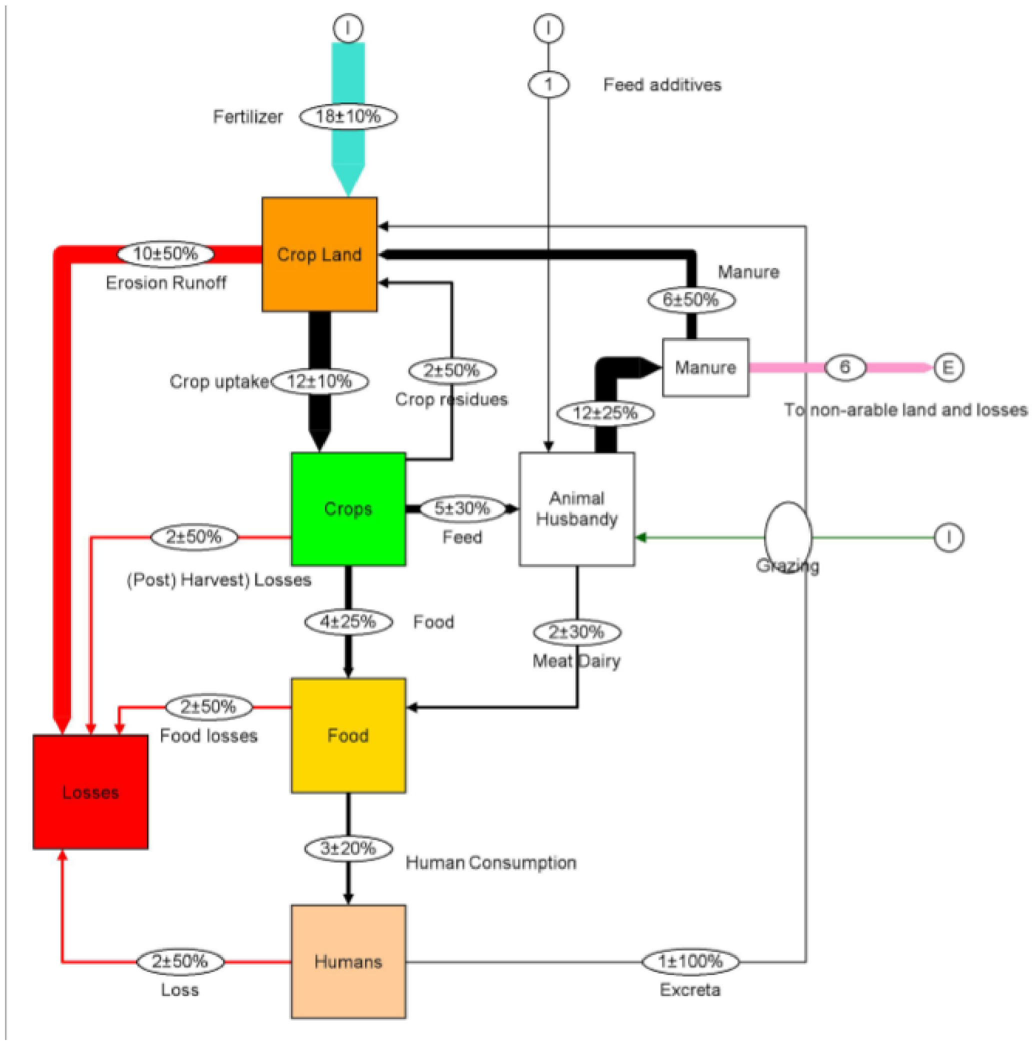


Figure 1. *Representation of the major global P-flows in (I), out (E) and through the food production system on arable land (after Cordell (2008; 2009) and taking also into account data by Smil (2000, 2007), Liu et al. (2008) and own calculations.*

6.3 P cycles

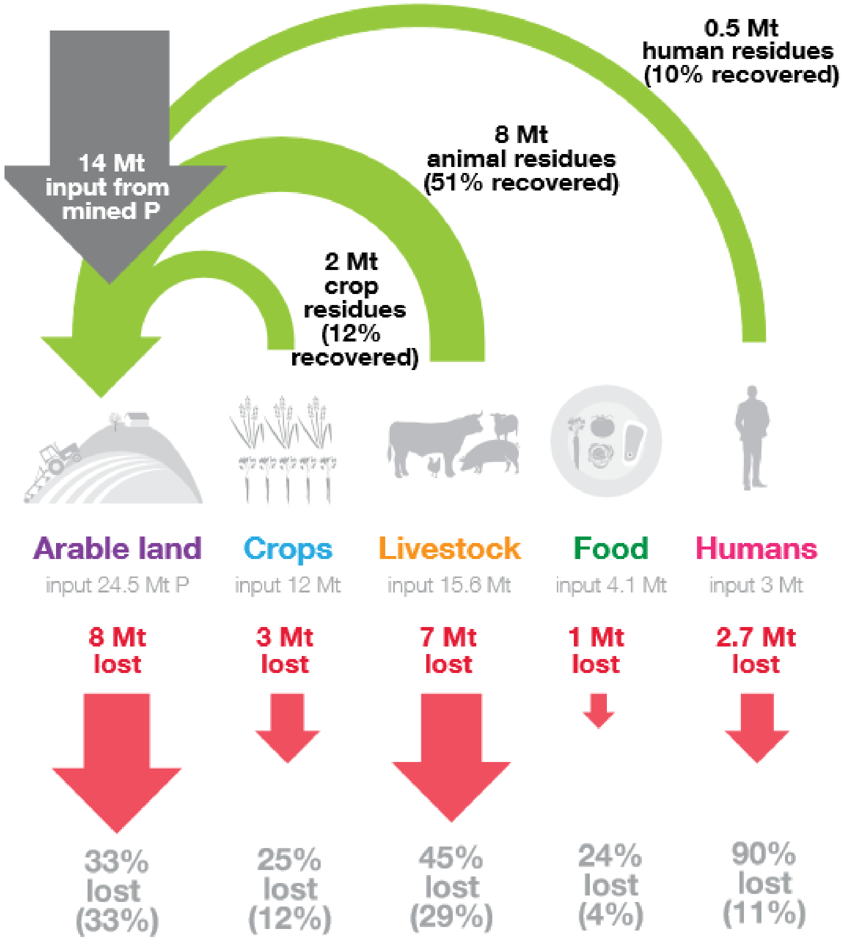


Figure 4. Simplified cycle of phosphorus in agriculture based on data from Cordell et al, 2009 and Cordell et al, 2011. Red arrows represent losses into water systems ultimately, and green arrows represent current recoveries into arable land from the different subsystems. The percentages under the red arrows represent the percentage losses from each subsystem, and shown in brackets are the percentage losses relative to the total input into agriculture land. For example, the livestock system loses about 45% of the phosphorus entering the livestock system itself, and this represents about a 29% loss of the phosphorus entering the agriculture system overall. (We have excluded the flow up to the input into farm system, but for example, losses in phosphorus mining and processing can also be significant.)

6.3 P cycles

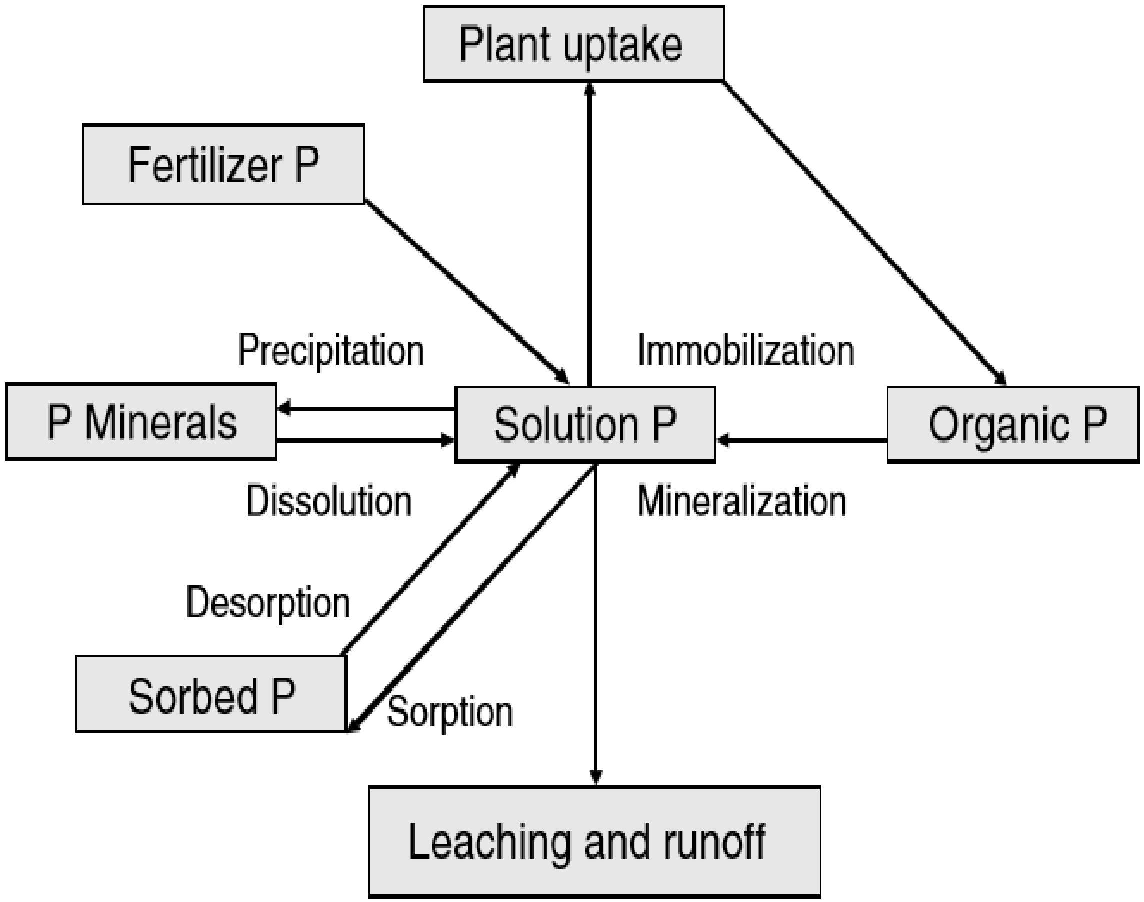
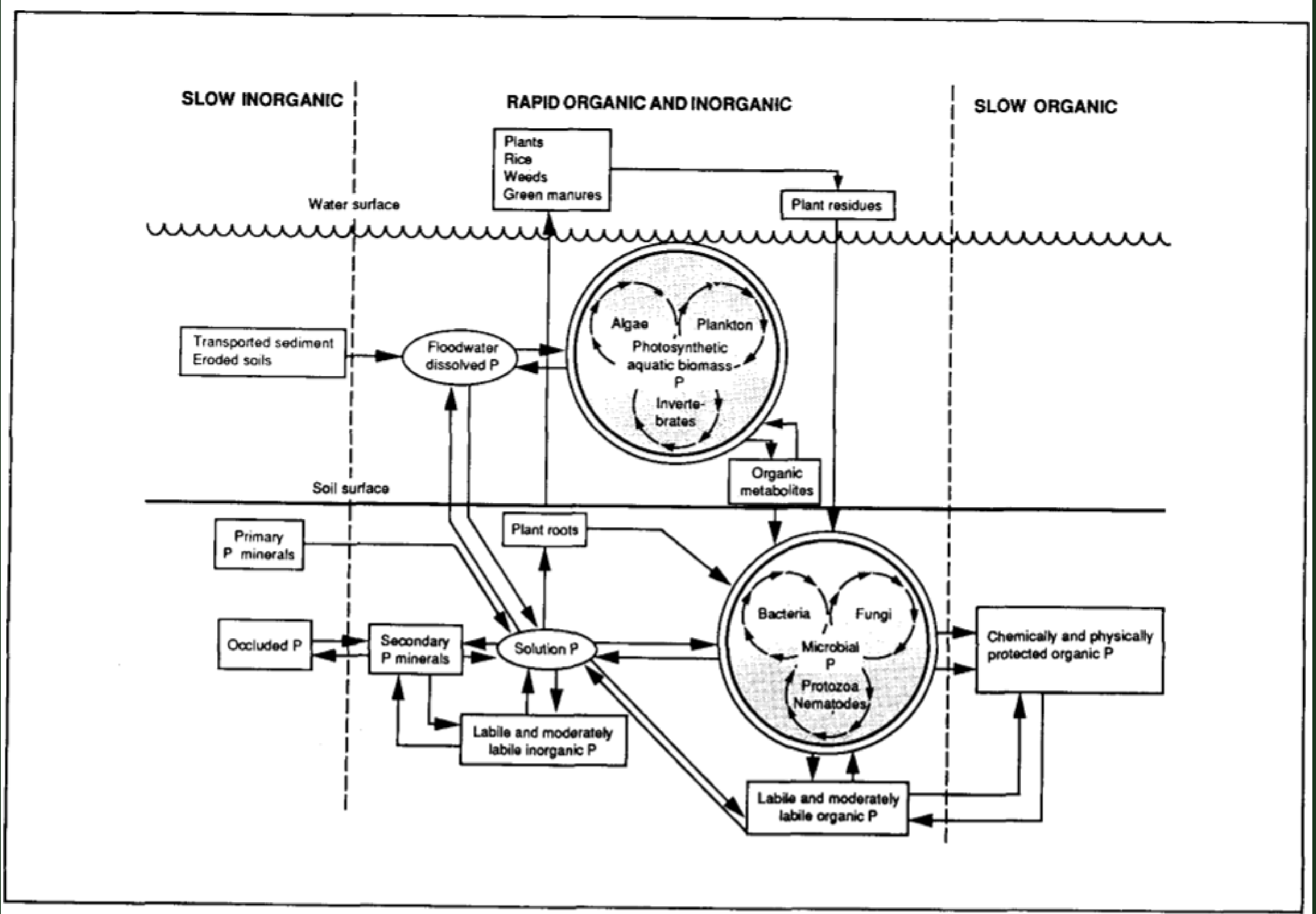


FIGURE 3.1 Phosphorus cycle in agricultural soils.

6.3 P cycles



1. Conceptual P cycle for a lowland rice soil.

6.3 P cycles

Table 1. Major global biospheric fluxes (Mt P $year^{-1}$) of phosphorus (Smil (2000) and Ruttenberg (2003)).

P-fluxes	Smil (2000)	Ruttenberg (2003)
Atmospheric deposition	3-4	3
Erosion and runoff	25-30	19-22
Plant uptake		
Terrestrial	70-100	71-200
Marine	900-1200	600-1100
Burial in marine sediments	20-35	8-9
Ocean to land (fisheries)		0.3
Minable P to land		12-142

6.3 P cycles

Table 2. Major biospheric reservoirs of phosphorus (sources: Ruttenberg (2003), Smil (2000), Jasinski (2008)).

P reservoir		Total storage (Mt P)	Reference
R1	Sediments (crustal rocks and soil > 60 cm deep and marine sediments)	800-4,000 * 10^6	1
R2	Soils (0-50 cm)	40,000-50,000	2
	Inorganic P	35,000-40,000	2
	Organic P	5,000-10,000	2
R7	Minable P	2,400-6,600	3
	Ocean	93,000	2
R4	Surface, 0-300 m (total dissolved P)	3000	1
R5	Deep sea, 300-3300 m (total dissolved P)	90,000	1
R3	Terrestrial phytomass	500-550	2
	Zoomass	30-50	2
	Anthropomass	3	2
R6	Marine phytomass	50-140	1
R8	Atmosphere	0.028	1

1= Ruttenberg, 2= Smil, 3= Jasinski.

6.3 P cycles

Dalam studi kesuburan tanah, siklus P ditinjau dari 3 aspek yaitu: input ke-, output dari- dan proses dalam tanah.

INPUT

1. Residu tanaman
2. Pupuk P
3. Kotoran hewan/binatang
4. Deposisi udara
5. Pelapukan batuan ber P

6.3 P cycles

- Output:

1. Terangkut panen
2. Run off dan erosi
3. Pencucian

6.3 P cycles

- Process:

1. P organik mengalami dekomposisi
2. P anorganik:

   a. Diambil tanaman dan biota tanah

   b. Diikat oleh komponen tanah: liat, logam (Al, Fe, Zn… Ca, .. Dll)

6.4. SOIL P RESOURCES

1. Pant Residue
2. P fertilizer
3. Animal manure/residue
4. Atmosferic Depostion
5. Rock P weathering

6.4.1 Plant Residue

Kadar P beberapa tanaman

Tanaman	Kadar P (kg/ha)	Tanaman	Kadar P (kg/ha)
Kc. Tunggak	2	Singkong	5
Kc. Tanah	5	Ubi jalar	5
Kc. Hijau	3		
Kc. Kedelai	2	TKKS (%)	0,22 (P_2O_5)
Kc. Panjang	6	Jerami padi (%)	0,07
Jagung Hibrida	7	Batang jagung	0,15
Jagung lokal	4		
Padi unggul	2		
Padi loka	2		

6.4.2 P fertilizer

- **Rock Phosphate**

  $Ca_{10}(PO_4)_6(OH)_2$

  Hydroxyapatite (bones, teeth) "bone-meal" bones in acid soils?

  $Ca_{10}(PO_4)_6F_{2\ or}\ Cl_2$ or OH_2

  Fluorapatite

  27-41% P_2O_5

  Total P in soils (90 to 2000 lb /acre, avg. of 800 in the surface horizon)

6.4.2 P fertilizer

Calcium Orthophosphates

P fertilizers:

water soluble

citrate soluble (dissolves more P than water)

<u>OSP ordinary superphosphate (0-20-0)</u>

- rock phosphate + sulfuric acid
- mixture of monocalcium phosphate and gypsum
- 16-22% P_2O_5 (90 % water soluble)
- 8-10% S as $CaSO_4$

6.4.2 P fertilizer

TSP triple or concentrated superphosphate (0-46-0)

- rock phosphate + phosphoric acid
- essentially all monocalcium phosphate
- 44 to 52% P_2O_5 (98% water soluble)
- < 3% S
- major phosphate mineral is monocalcium phosphate monohydrate (MCP)

6.4.2 P fertilizer

DAP Diammonium phosphate (18-46-0)

- Reacting wet process H_3PO_4 with NH_3
- 46-53% P_2O_5

MCP monocalcium phosphate monohydrate $Ca(H_2PO_4)_2$ $2H_2O$ (highly water soluble)

DCPD dicalcium phosphate dihydrate $CaHPO_4$* $2H_2O$ - brushite

DCP dicalcium phosphate $CaHPO_4$, 53% P_2O_5 - monetite

congruent dissolution of $Ca(H_2PO_4)_2$ $2H_2O$ into Ca^{++} and H_2PO_4 ions occurs at a pH of 4.68

6.4.2 P fertilizer

Table 3. Production and reserves of rock phosphate[3] (in 1000 metric tons rock phosphate).

	Mine production		Reserves	Reserve base	Reserves (%)	Reserve base (%)
	2006	2007				
United States	30,100	29,700	1,200,000	3,400,000	6.7	6.8
Australia	2,300	2,200	77,000	1,200,000	0.4	2.4
Brazil	5,800	6,000	260,000	370,000	1.4	0.7
Canada	550	500	25,000	200,000	0.1	0.4
China	30,700	35,000	6,600,000	13,000,000	36.7	26.0
Egypt	2,200	2,300	100,000	760,000	0.6	1.5
Israel	2,950	3,000	180,000	800,000	1.0	1.6
Jordan	5,870	5,700	900,000	1,700,000	5.0	3.4
Morocco and W. Sahara	27,000	28,000	5,700,000	21,000,000	31.7	42.0
Russia	11,000	11,000	200,000	1,000,000	1.1	2.0
Senegal	600	800	50,000	160,000	0.3	0.3
South Africa	2,600	2,700	1,500,000	2,500,000	8.3	5.0
Syria	3,850	3,800	100,000	800,000	0.6	1.6
Togo	1,000	1,000	30,000	60,000	0.2	0.1
Tunisia	8,000	7,700	100,000	600,000	0.6	1.2
Other countries	7,740	8,000	890,000	2,200,000	4.9	4.4
World total (rounded	142,000	147,000	18,000,000	50,000,000	100.0	100.0
In Mt of P[4]	18.6	19.3	2400	6600		

[3] Rock phosphate that is used as a feed stock for phosphoric acid or elemental phosphorus usually is referred to as marketable phosphate rock, regardless of whether it has been beneficiated. The generic term, phosphate rock, can refer to either igneous or sedimentary phosphate-bearing minerals used as an ore.

[4] The reserve base is not standardized to 30% P_2O_5 but it would be a good estimate of the potential P_2O_5 that may be contained (Jasinski, pers. comm.).

Table 9.6 Summary of Compounds Formed from the Reaction of Phosphate Fertilizers with Soils or Soil Constituents

Compound	Mineral name	Compound	Mineral name
$AlPO_4 \cdot 2H_2O$	Variscite	$FePO_4 \cdot 2H_2O$	Metastrengite
$AlPO_4 \cdot 2H_2O$	Metavariscite	$Fe_3(PO_4)_2 \cdot 8H_2O$	Vivianite
$Al(NH_4)_2H(PO_4)_2 \cdot 4H_2O$	—	$FeNH_4(HPO_4)_2$	—
$Al_2(NH_4)_2H_4(PO_4)_4 \cdot H_2O$	—	$Fe_3NH_4H_6(PO_4)_6 \cdot 6H_2O$	—
$Al_5(NH_4)_3H_6(PO_4)_8 \cdot 18H_2O$	NH_4-taranakite	$Fe_3KH_6(PO_4)_6 \cdot 6H_2O$	—
$AlNH_4PO_4OH \cdot 2H_2O$	—	$Fe_2K(PO_4)_2OH \cdot 2H_2O$	K-leucophosphite
$AlNH_4PO_4OH \cdot 3H_2O$	—	$MgHPO_4 \cdot 3H_2O$	Newberryite
$Al_2NH_4(PO_4)_2OH \cdot 2H_2O$	—	$Mg_3(PO_4)_2 \cdot 4H_2O$	—
$Al_2NH_4(PO_4)_2OH \cdot 8H_2O$	—	$Mg_3(PO_4)_2 \cdot 22H_2O$	—
$AlKH_2(PO_4)_2 \cdot H_2O$	—	$MgNH_4PO_4 \cdot 6H_2O$	Struvite
$Al_5K_3H_6(PO_4)_8 \cdot 18H_2O$	K-taranakite	$Mg(NH_4)_2(HPO_4)_2 \cdot 4H_2O$	Schertelite
$Al_2K(PO_4)_2OH \cdot 2H_2O$	Leucophosphite	$Mg_3(NH_4)_2(HPO_4)_4 \cdot 8H_2O$	Hannayite
$AlKPO_4OH \cdot 0.5H_2O$	—	$MgKPO_4 \cdot 6H_2O$	—
$AlKPO_4OH \cdot 1.5H_2O$	—	$Mg_2KH(PO_4)_2 \cdot 15H_2O$	—
$Al_2K(PO_4)_2(F,OH) \cdot 3H_2O$	Minyulite	$Al(NH_4)_2P_2O_7OH \cdot 2H_2O$	—
$CaHPO_4$	Monetite	$Ca_2P_2O_7 \cdot 2H_2O$	—
$CaHPO_4 \cdot 2H_2O$	Brushite	$Ca_2P_2O_7 \cdot 4H_2O$	—
$Ca_8H_2(PO_4)_6 \cdot 5H_2O$	Octocalcium phosphate	$Ca_3H_2(P_2O_7)_2 \cdot 4H_2O$	—

Table 9.6 Summary of Compounds Formed from the Reaction of Phosphate Fertilizers with Soils or Soil Constituents (Continued)

Compound	Mineral name	Compound	Mineral name
$Ca_{10}(PO_4)_6(OH)_2$	Hydroxyapatite	$Ca(NH_4)_2P_2O_7 \cdot H_2O$	—
$Ca_{10}(PO_4)_6F_2$	Fluorapatite	$Ca_3(NH_4)_2(P_2O_7)_2 \cdot 6H_2O$	—
$CaAlH(PO_4)_2 \cdot 6H_2O$	—	$Ca_5(NH_4)_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaAl_6H_4(PO_4)_3 \cdot 20H_2O$	—	$CaNH_4HP_2O_7$	—
$CaNH_4PO_4 \cdot H_2O$	—	$Ca_2NH_4H_3(P_2O_7)_2 \cdot 3H_2O$	—
$Ca(NH_4)_2(HPO_4)_2 \cdot H_2O$	—	$CaK_2P_2O_7$	—
$Ca_2NH_4H_7(PO_4)_4 \cdot 2H_2O$	NH_4-Flatt's salt	$Ca_3K_2(P_2O_7)_2 \cdot 2H_2O$	—
$Ca_2(NH_4)_2(HPO_4)_3 \cdot 2H_2O$	—	$Ca_6K_2(P_2O_7)_3 \cdot 6H_2O$	—
$CaKPO_4 \cdot H_2O$	—	$Ca_2KH_3(P_2O_7)_2 \cdot 3H_2O$	—
$CaK_3H(PO_4)_2$	—	$CaNa_2P_2O_7 \cdot 4H_2O$	—
$Ca_2KH_7(PO_4)_4 \cdot 2H_2O$	K-Flatt's salt	$Fe(NH_4)_2P_2O_7 \cdot 2H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 5H_2O$	—	$Mg(NH_4)_2P_2O_7 \cdot 4H_2O$	—
$CaFe_2H_4(PO_4)_4 \cdot 8H_2O$	—	$Mg(NH_4)_6(P_2O_7)_2 \cdot 6H_2O$	—
$Ca_3Mg_3(PO_4)_4$	—	$Mg(NH_4)_2H_4(P_2O_7)_2 \cdot 2H_2O$	—
$FePO_4 \cdot 2H_2O$	Strengite	$Ca(NH_4)_3P_3O_{10} \cdot 2H_2O$	—

From Sample et al., 1986. *The Role of Phosphorus in Agriculture*, Khasawneth, F.E., Sample, E.C., and Kamprath, E.J., Eds., p. 284. With permission of American Society of Agronomy.

Table 9.7 General Composition of Phosphate Fertilizers

Material	Total nitrogen (%)	Total potassium (%)	Total sulfur (%)	Total calcium (%)	Total magnesium (%)	Phosphorus	
						Total[a] (%)	Available[b] (% of total)
Ordinary superphosphate (OSP)	—	—	11–12	18–21	—	7–9.5	97–100
Conc. (triple) superphosphate (CSP)	—	—	0–1	12–14	—	19–23	96–99
Enriched superphosphate	—	—	7–9	16–18	—	11–13	96–99
Ammoniated OSP	2–5	—	10–72	17–21	—	6.1–8.7	96–98
Ammoniated CSP	4–6	—	0–1	12–14	—	19–21	96–99
Dicalcium phosphate	—	—	—	29	—	23	98
Ammonium phosphates[c]							
21-53-0	21	—	—	—	—	23	100
21-61-0	21	—	—	—	—	27	100
11-48-0	11	—	0–2	—	—	21	100
16-48-0	16	—	0–2	—	—	21	100
18-46-0	18	—	0–2	—	—	20	100
16-20-0	16	—	14	—	—	8.7	100

Table 9.7 General Composition of Phosphate Fertilizers (Continued)

Material	Total nitrogen (%)	Total potassium (%)	Total sulfur (%)	Total calcium (%)	Total magnesium (%)	Phosphorus: Total[a] (%)	Phosphorus: Available[b] (% of total)
Ammonium phosphate nitrate	30	—	—	—	—	4	100
Ammonium polyphosphate	15	—	—	—	—	25	—
Potassium phosphate	—	29–45	—	—	—	18–22	100
Magnesium ammonium phosphate	8	—	—	—	—	14	17
Raw rock phosphate	—	—	—	33–36	—	11–17	14–65
Basic slag	—	—	0.2	32	3	3.5–8	62–94
Defluorinated phosphate rock	—	—	—	20	—	9	85
Phosphate rock-magnesium silicate	—	—	—	20	8.4	10	85
Rhenania phosphate	—	—	—	30	0.3	12	97
Potassium metaphosphate	—	29–32	—	—	—	24–25	—

[a] Values given as elemental P. Fertilizers are generally marketed giving %P_2O_5, which can be obtained by multiplying P value with 2.27. For example, see the grades of ammonium phosphates in this table.

[b] By neutral 1.0 N ammonium citrate procedure.

[c] Ammonium phosphate grades expressed as %N, %P_2O_5, %K_2O.

From Tisdale et al., 1993. *Soil Fertility and Fertilizers*, 5th ed., p. 208. With permission of Prentice-Hall, Inc., Upper Saddle River, NJ.

6.4.3 Animal manures/residue

Table 10. The amounts of feces and phosphorus produce by different animals. [a]

Animal	Size	Total Manure Production	Phosphorus oxide (P_2O_5)	Phosphorus oxide (P_2O_5)
	kg	kg d^{-1}	kg d^{-1}	kg yr^{-1}
Dairy Cow	68	5.4	0.0104	4128
	113	9.1	0.0204	6804
	227	18.6	0.0372	13608
	454	37.2	0.0753	27670
	635	52.2	0.1502	52618
Beef Cattle	227	13.6	0.0576	20412
	340	20.4	0.0866	30845
	454	27.2	0.1134	41278
	567	34.0	0.1442	51710
Swine				
Nursery Pig	16	1.0	0.0054	1950
Growing Pig	29	1.9	0.0223	3720
Finishing Pig	68	4.4	0.0500	8618
Finishing Pig	91	5.9	0.0680	11340
Boar	159	5.0	0.2676	9979
Sheep	45	1.8	0.0068	2495
Poultry-Layers	2	0.10	0.00011	422
Poultry-Broilers	1	0.06	0.00006	195
Horse	454	20.4	0.0476	17690

[a] Midwest Plan Service (1985).

6.4.3 Animal manures/residue

Pupuk kandang	Kadar P (%)	Pupuk kandang	Kadar P (%)
Sapi	0,2	Kambing	0,73
Ayam	0,8		
Domba	0,19-0,5		
Kuda	0,3		

SOIL P LOSS

1. Run off and erosion
2. Leaching
3. Removal by crop harvest

1. Run off and erosion

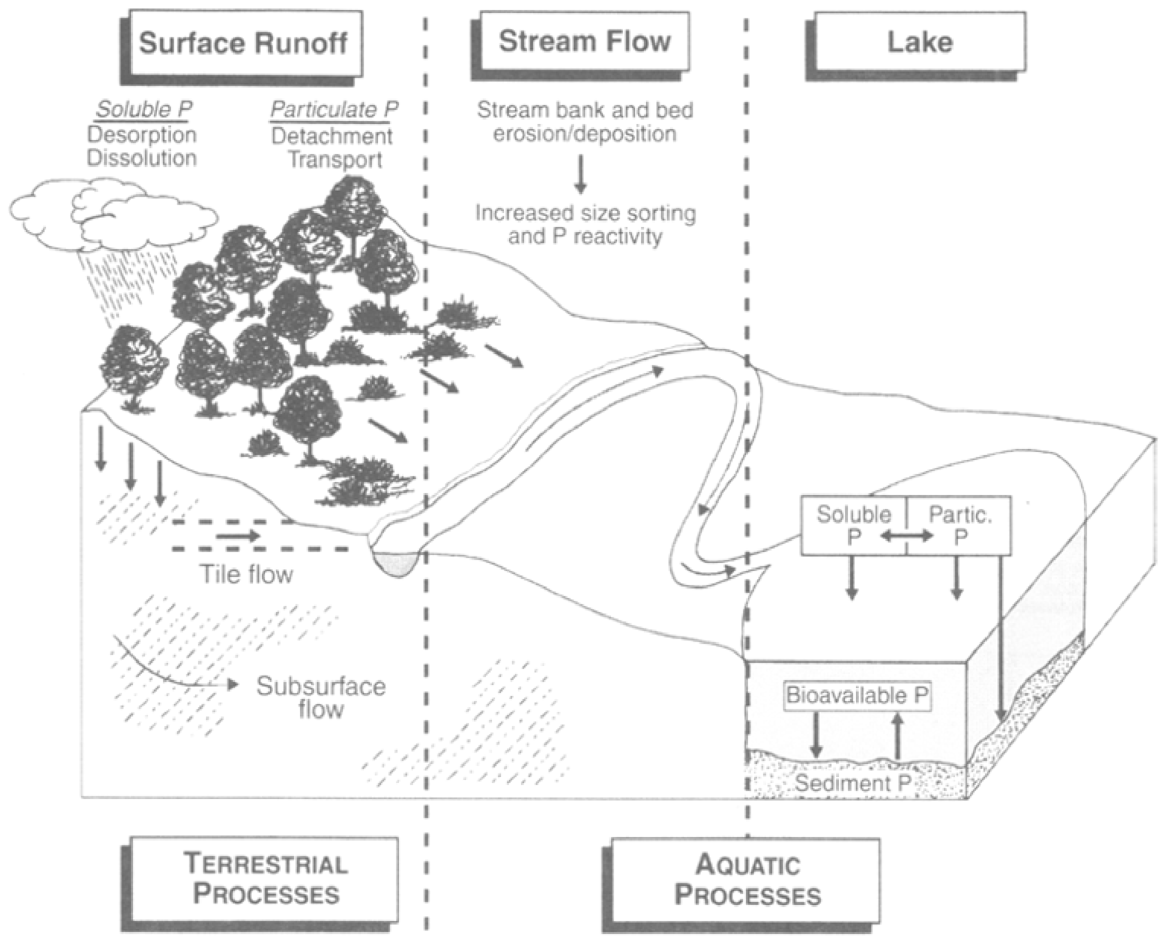


Figure 1. Phosphorus transport includes terrestrial and aquatic processes (Pierzynski et al., 2000).

1. Run off and erosion

Table 2 Summary of the main problems causing phosphorus loss from agricultural soils with relevant pathways for major soil textures in river delta soils of north-western Europe

Soil textures	Main problem causing P loss	Pathways for P loss
Sandy soils	Excessive inputs and build-up of soil P	Subsurface runoff
Peat soils	Mineralization of organic matter, or easily soluble P minerals in marine clay sediments just below peat layers	Subsurface runoff, or seepage through the topsoil to surface water
Clay soils	Incidental loss of freshly applied P	Surface runoff, or preferential flow

1. Run off and erosion

Tabel 1. Pengaruh vegetasi dan lereng terhadap erosi dan kehilangan hara.

Perlakuan	Lereng (%)	Erosi (ton/ha)	Aliran Permukaan (mm)	Unsur hara yang hilang (kg/ha)				
				N	P	K	Ca	Mg
Tanah bera, dibajak setiap bulan	22	225.4	1730	25	0.98	24	238	152
Rumput ternak	22	7.1	513	7	0.15	6	25	26
Tanaman kopi muda	45	1.8	190	8	0.04	2	6	7
Kopi muda dengan teras	45	0.2	410	4	0.14	4	8	9
Tanaman kopi tua tanpa konservasi	55	0.6	59	1	0.08	1	2	2

Sumber : Castro dan Rodriguez (1958) dalam Sanchez, 1976.

1. Run off and erosion

Table 2. Runoff, soil and nutrient losses from different cropping systems

Treatments	Runoff (m³)	Soil Loss (t ha⁻¹)	Nutrient losses in sediment OM kg ha⁻¹	N	P	K	Nutrient losses in runoff N	P	K
Average runoff, soil and nutrient losses during 3 *rabi* season									
Wheat	0.23a	1.97b	40b	0.11b	0.05b	0.48b	0.83a	2.75a	3.14a
Barley+Lentil	0.21a	1.72a	37a	0.08a	0.02a	0.39a	0.65a	2.71a	2.98a
Bare Soil	0.37b	2.65c	71c	0.18c	0.07c	0.60c	1.23b	5.06b	3.60b
LSD (0.05)	0.04	0.106	2.351	0.018	0.013	0.052	0.211	1.313	0.233
Average runoff, soil and nutrient losses during 3 *kharif* season									
Maize	3.44a	10.46b	128b	0.45b	0.22b	4.71b	5.96a	14.9a	113a
Maize+Mungbean	2.74a	8.52a	104a	0.30a	0.17a	3.66a	5.40a	12.1a	99a
Bare Soil	4.47b	16.99c	236c	0.77c	0.37c	7.30c	8.09c	23.5b	143b
LSD (0.05)	0.84	1.510	17.21	0.112	0.031	0.873	1.51	5.43	18.22
Average runoff, soil and nutrient losses for 3-years									
Monocropping	3.67a	12.44b	168b	0.56b	0.27b	5.18b	6.79a	17.7a	116a
Intercropping	2.95a	10.24a	141a	0.38a	0.19a	4.05a	6.05a	14.8a	102a
Bare Soil	4.83b	19.64c	307c	0.95c	0.44c	7.89c	9.32b	28.5b	147b
LSD (0.05)	0.78	1.458	15.34	0.113	0.035	0.792	1.36	4.83	20.31

Means followed by same letters in each column do not differ significantly from one another at 5% level of probability using LSD Test.

1. Run off and erosion

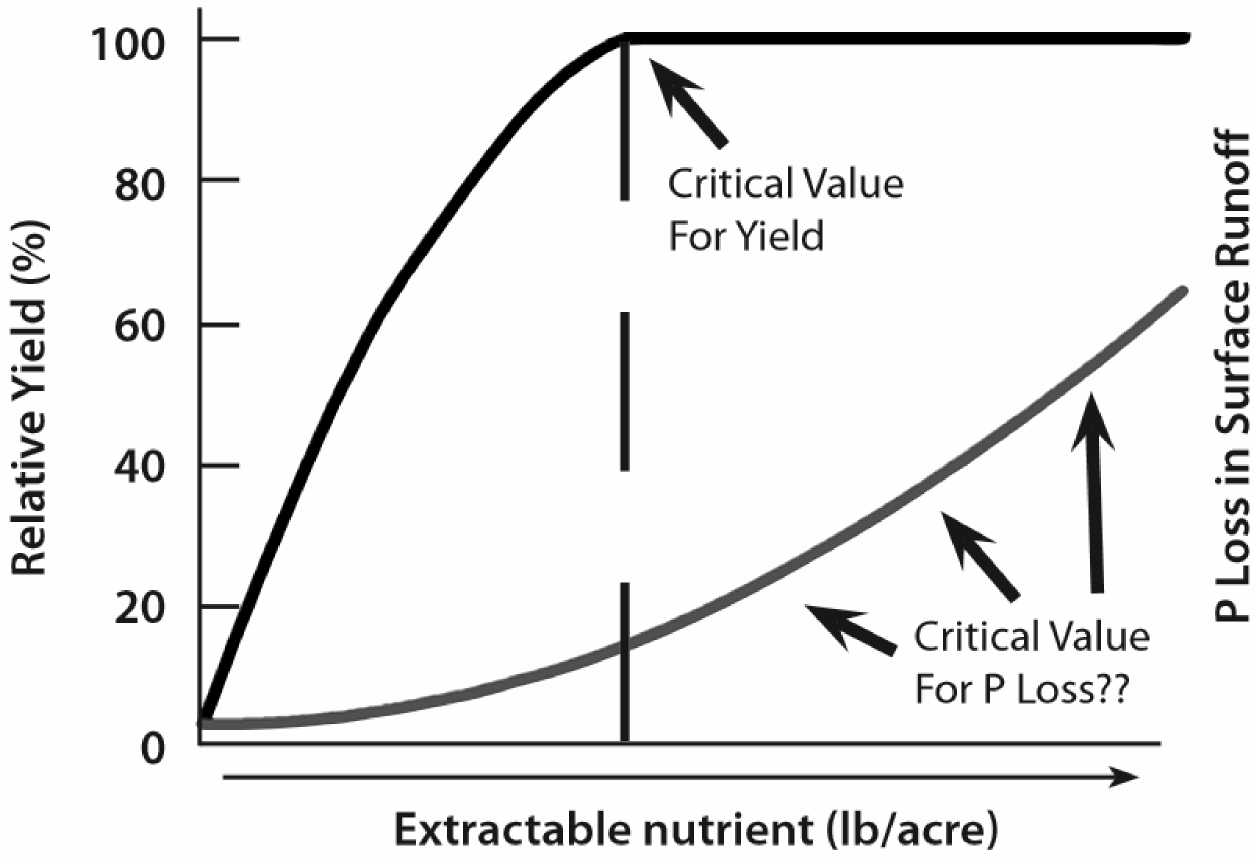


Fig. 6. Relationships showing that expected crop yields and the potential for phosphorus losses in surface runoff increase with increasing soil test phosphorus. Although we can accurately predict crop yields using soil test procedures, we cannot use the same relationship to determine the critical value for runoff phosphorus losses

2. Leaching

Table 6: *Concentrations, μg/L, of different phosphorus fractions lost in drainage during 1994-95 from four grassland soil types. (adapted from Turner and Haygarth, 2000).*

	Total P, μg/L			Reactive P, μg/L		
	Total	<0.45 μm	>0.45 μm	Total	<0.45 μm	>0.45 μm
Silty clay						
Mean	179	130	49	132	117	16
Range	136-247	85-210	10-107	90-223	81-210	19480
Flow weighted mean	163	109	54	107	97	10
Clay loam						
Mean	162	117	45	105	95	10
Range	72-446	62-261	5-184	33-234	29-191	16072
Flow weighted mean	94	73	20	66	59	6
Sandy loam						
Mean	65	39	26	39	25	14
Range	33-109	10-91	10-53	12-108	7-56	3-52
Flow weighted mean	53	28	25	34	20	14
Sand						
Mean	240	71	169	97	63	34
Range	56-1145	36-161	10-984	33-359	29-157	4-202
Flow weighted mean	88	48	39	52	43	9

P Budget

Table 13. Phosphorus budgets for the worlds cropland (after Smil (2000) and Liu et al. (2008)).

Flows	Annual fluxes in Mt P per year	
	Smil (2000)	Liu *et al.* (2008)
	Reference mid-1990s	Reference 2004
Inputs	24-29	23
• Weathering	2	1.6
• Atmos.deposition	1-2	0.4
• Org. recycling	7-10	6.2
• Crop residues	1-2	2.2
• Animal manure	6-8	2.5
• Human waste	?	1.5
• Fertilizers	14-15	14.7
Removals	11-12	12.7
• Crops	8-9	8.2
• Crops residues	3	4.5
Losses	13-15	19.8
• Erosion		19.3
• Runoff		0.5
Balance	0-2	-9.6

3. Removal by Crop Harvest

Table 15. Phosphorus removal rates for different crops. Phosphorus removal ($kg\ ha^{-1}$) is estimated by the mean P concentration and the mean yield of the crop for the United States. All values are expressed on a fresh weight basis. [a]

Crop or commodity	P removal ($kg\ ha^{-1}$)	Crop or commodity	P removal ($kg\ ha^{-1}$)
	Specialty crops		
Apple (*Malus pumila* Mill.)	5.9	Orange (*Citrus sinensis*)	11.6
Apricot (*Prunus armeniaca* L.)	5.9	Parsley (*Petroselinum crispum* Mill. Manof.)	3.9
Asparagus (*Asparagus officinalis*)	19.6	Parsnip (*Pastinaca sativa* L.)	19.6
Bean, lima (*Phaseolus limensis* mac F.)	7.7	Peach (*Prunus persica* L.)	3.9
Bean, snap (*Phaseolus vulgaris* L.)	11.6	Pear (*Pyrus communis* L.)	3.9
Beat, table (*Beta vulgaris*)	3.9	Pea (*Pisum sativum*)	3.9
Blackcherry (*Rubus ursinus* Cham. & Schlect.)	3.9	Pepper (*capsicum annum* L.)	5.9
Broccoli (*Brassica olacea* L. *botrylis* L.)	11.6	Potato (*Solanum tuberosum* l.)	13.3
Cabbage (*Brassica oleracea* L. *capitata* L.)	11.6	Prune (*Prunophora* Focke)	7.7
Cantaloupe (*Cucumis Melo cantalupensis*)	18.7	Pumpkin (*Curcubita pepo* L.)	5.9
Carrot (*Daucus carota* L.)	11.6	Raspberry (*Rubus idealis* L.)	3.9
Cauliflower (*Brassica oerlacea* L. *botrylis* L.)	13.3	Rutabaga (*Brassica napus napobrassica*)	7.7
Celery (*Apium graveolens*)	72.3	Spinach (*Spinacia oleracea*)	15.6
Cucumber (*Cucumis sativus* L.)	3.9	Squash (*Cucurbia ssp.* L.)	3.9
Grape (*Vitis vinifera* L.)	11.6	Strawberry (*Fragaria ssp.* L.)	3.9
Hops (*Humulus lupulus* L.)	17.8	Sugar cane (*sorhum saccharatum*)	39.2
Kale (*Brassica olacea* L. *acephala* D.C)	7.7	Sweet corn (*Zea mays* L.)	3.9
Lettuce (*Lactuca sative* L.)	11.6	Sweet potato (*Ipomoea batatas* L. Lem.)	9.8
Muskmelon (*Cucumis melo* L.)	5.9	Tobacco (*Nicotiana tabacum*)	5.9
Okra (*Hibiscus esculentus* L.)	3.9	Tomato (*Lycopersicon esculentum* Mill.)	21.4
Onion (*Allium cepa* L.)	15.6	Turnip (*Brassica rapa* L. *rapifera*)	9.8
	Row crops, small grains		
Barley grain (*Hordeum vulgare* L.)	5.9	Rice grain (*Oryza sativa* L.)	7.8
Barley straw (*Hordeum vulgare* L.)	2.0	Rice straw (*Oryza sativa* L.)	3.9
Bean, dry (*Phaseolus vulgaris* L.)	9.8	Rye grain (*Secale cerale* L.)	3.9
Corn grain (*Zea mays* L.)	20.5	Rye grain (*Secale cerale* L.)	3.1
Corn stover (*Zea mays* L.)	14.3	Sorghum grain (*Sorghum vulgare* L.)	9.8
Cotton, seed and lint (*Gossypium hirsutum* L.)	7.8	Sorghum stover (*Sorghum vulgare* L.)	7.8
Cotton, stalks, leaves, burs (*Gossypium hirsutum* L.)	3.9	Soybean grain (*Glycine max* Merrill.)	15.6
Flax grain (*Linum usitatissimum L.*)	3.9	Soybean straw (*Glycine max* Merrill.)	3.9
Flax straw (*Linum usitatissimum L.*)	2.0	Sugar beet roots (*Beta vulgaris saccharifera* L.)	19.6
Oat grain (*Avena sativa* L.)	7.8	Sugar beet tops (*Beta vulgaris saccharifera* L.)	13.4
Oat straw (*Avena sativa* L.)	5.9	Sunflower (*Helianthus annus* L.)	15.6
Peanut, nuts (*Arachis hypogaea* L.)	5.9	Wheat grain (*Triticum aestivum* L.)	9.8
Peanut, vines(*Arachis hypogaea* L.)	11.6	Wheat Straw (*Triticum aestivum* L.)	2.0
	Forage Crops		
Alfaalfa (*Medicago sativa* L.)	27.7	Lespedeza (*Lespedeza striata* (Thunb.) H. & A.)	11.6
Bluegrass (*Poa annua* L.)	11.6	Orchardgrass (*Dactylis glomerata* L.)	25.0
Coastal bermudagrass (*Cynodon dactylon* L.)	56.2	Red clover (*Trifolium prantese* L.)	17.8
Corn silage (*Zea mays* L.)	31.2	Sudangrass (*Soghum vulgare sudanense* (Piper) Hitchc.)	13.4
Fescue, tall (*Festuca arundicacea* Schreb.)	31.2	Sweet clover (*Meliotis alba* Desr.)	27.7
Johnsongrass (*Sorghum halepense* L. Pers.)	74.1	Timothy (*Phleum pratense* L.)	11.6
Ladino clover (*Trifolium rapens* L.)	17.8		

[a] Pierzynski and Logan (1993).

6.5. SOIL P

Table 6. The common chemical forms of P in soil and their characteristics and potential mobility. [a]

Form	Characteristics or Implication
INORGANIC in solution	
Orthophosphate (H_3PO_4)	Readily mobile but easily adsorbed/immobilized
INORGANIC in the soil matrix	
Apatites Hydroxyapatite ($Ca_{10}(PO_4)_6OH_2$) Fluorapatite ($Ca_{10}(PO_4)_6F_2$)	Very low solubility. Tend to be present more in nonacid soils than in acid.
Sodium phosphates Pyrophosphate ($Na_4P_2O_7 \cdot H_2O$)	Soluble. No known information on the implications
Polyphosphate $(Na_3PO_3)n$	
Other calcium phosphates Monocalcium phosphate ($Ca(H_2PO_4)_2 \cdot H_2O$) Dicalcium phosphate ($Ca(HPO_4) \cdot 2H_2O$) Tricalcium phosphate ($Ca_3(PO_4)_2$) Octacalcium phosphate ($Ca_8H_2(PO_4)_6 \cdot 5H_2O$)	Tend to form when fertilizers are added to nonacid soils.
Aluminum phosphates Variscite ($AlPO_4 \cdot 2H_2O$) Taranakite ($H_6K_3Al_5(PO_4)_8 \cdot 18H_2O$) Wavelite ($Al_8(OH_3(PO_4))_2$)	Tend to form when fertilizers are added to acid soils that have aluminum.
Iron phosphates Vivianite ($Fe_3(PO_4)_2 \cdot 8H_2O$) Strengite ($FePO_4 \cdot H_2O$)	Tend to form when fertilizers are added to acid soils that have iron.
Surface-adsorbed P	Adsorbed on calcium, iron and aluminum compounds.
ORGANIC in soil matrix	
Phytic acid or Inositol hexaphosphates (IHP:($C_6H_6O_6$)(PO_3)$_6$)	Not generally thought to be easily mobile except in sandy soils: maybe highly sorbed but have been noted in lake sediments
Phosphate diesters (nucleic acids, DNA, RNA, phospholipids)	Probably mobile but confirmation is required
Glucose P ($_D$-Glucose-6-phosphate; $_D$-Glucose-1-phosphate)	Leaches through sandy soils
Phosphonates (R-PO_3)	No known information on the implications
Polyphosphanates (ATP,AMP)	No known information on the implications

[a] Haygarth and Jarvis (1999); Troeh and Thompson (1993); Anderson (1980); McClellan and Gremillion (1980); Sample et al. (1980).

6.5. SOIL P

Table 9.1 Organic P Content of Surface Mineral/Organic Soils in Relation to Soil Texture

Soil texture	Number of samples	Organic P (mg kg^{-1}) Soil	Organic P % of total P
Mineral soils			
Sands	194	121	34.1
Loams	663	250	39.9
Clay loams and clays	309	332	41.4
Organic soils			
Organic loams	5	523	58.9
Peats	85	579	65.4

Adapted from Harrison (1987).

6.5. SOIL P

Table 9.2 Forms of Organic P in Soils

Form	Soil ($mg\ kg^{-1}$)	% of organic P
Inositol phosphate	1.4–356	0.3–62
Nucleic acids	0.1–97	0.1–65
Phospholipids	0.4–17	0.03–5.4

Adapted from Harrison (1987).

6.5. SOIL P

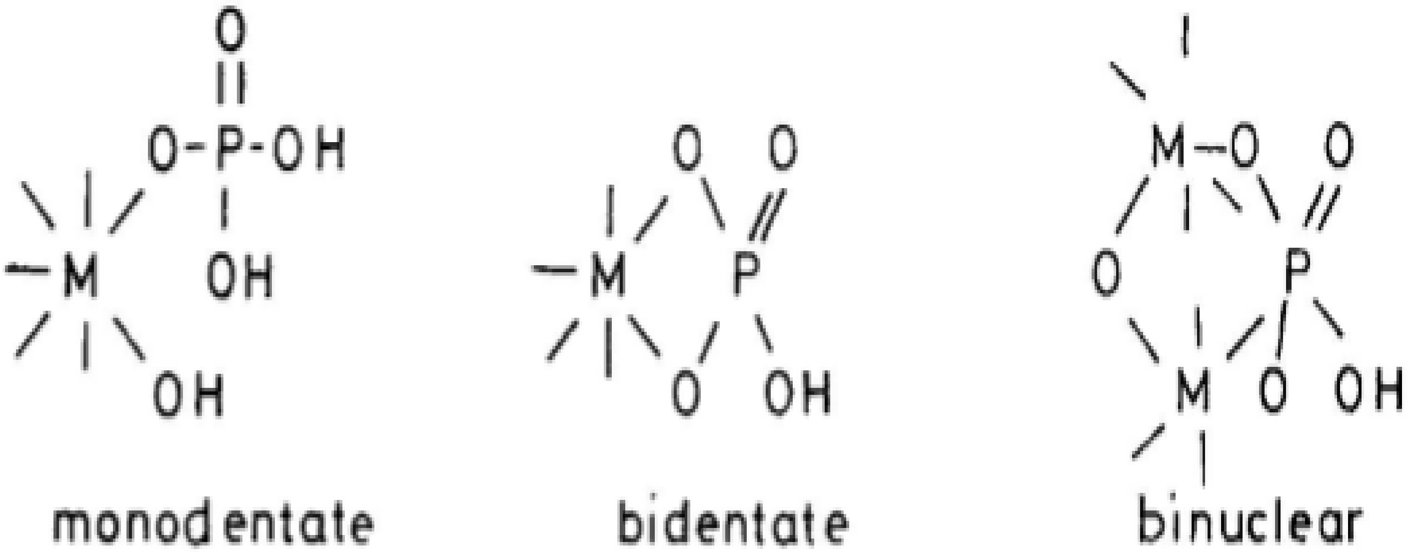


Figure 9.5. Reversible (monodentate) and irreversible (bidentate and binuclear) adsorption of P. (From Hingston et al., 1974; Fixen and Grove, 1990.)

6.5. SOIL P

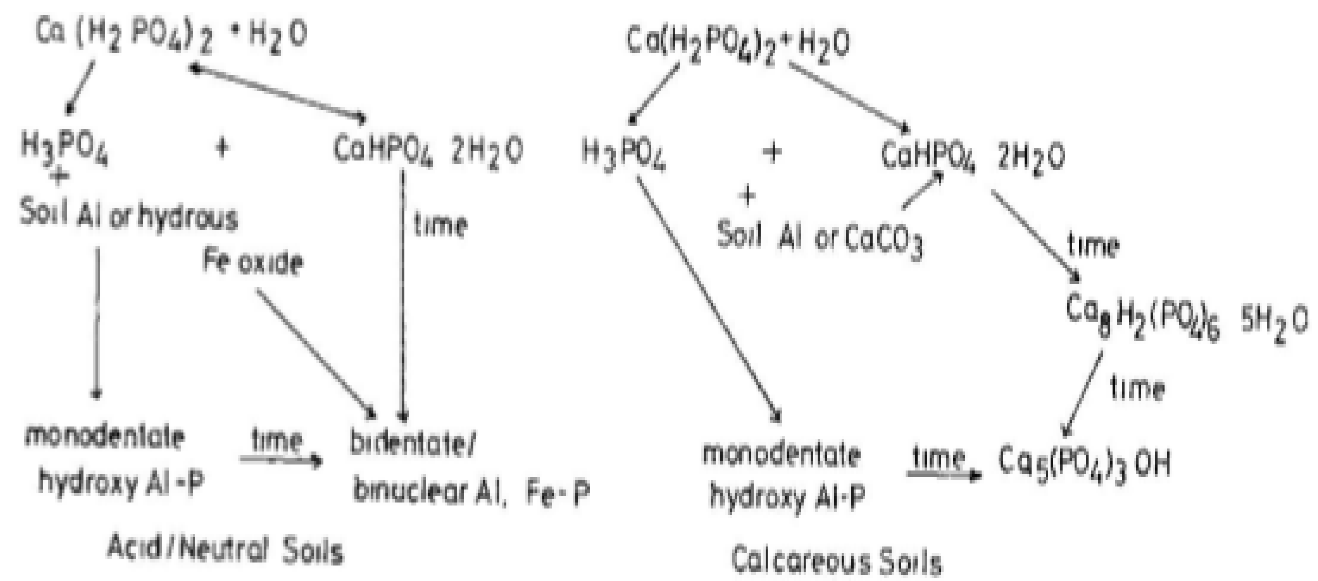
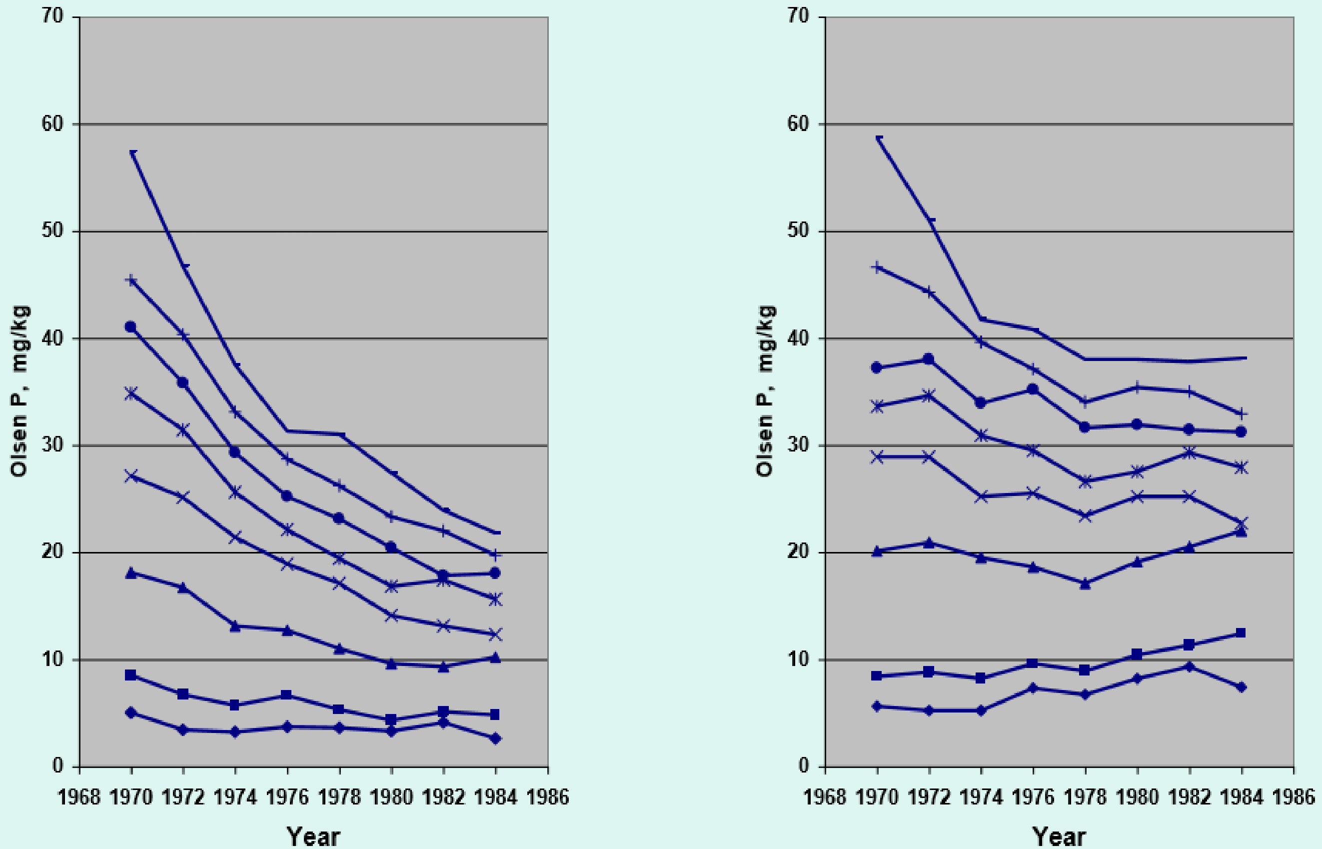


Figure 9.8. Transformations of monocalcium phosphate in soils. (Adapted from Thomas and Peaslee, 1973.)

6.5. SOIL P

Saxmundham: changes in Olsen P with treatment and time



No fresh added after 1968

18 kg/ha/yr 1969-77
26 kg/ha/yr 1978-83

6.5. SOIL P

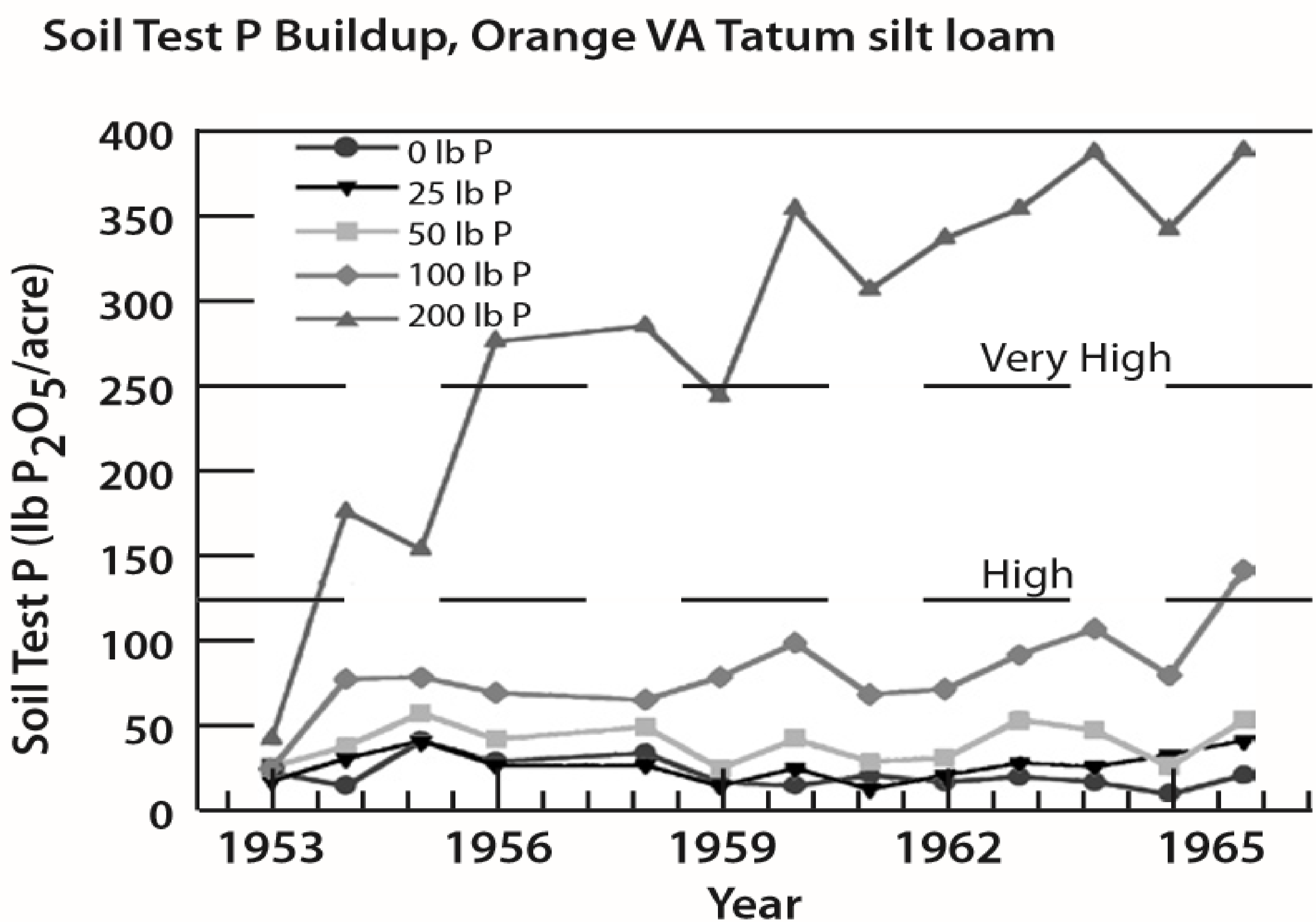
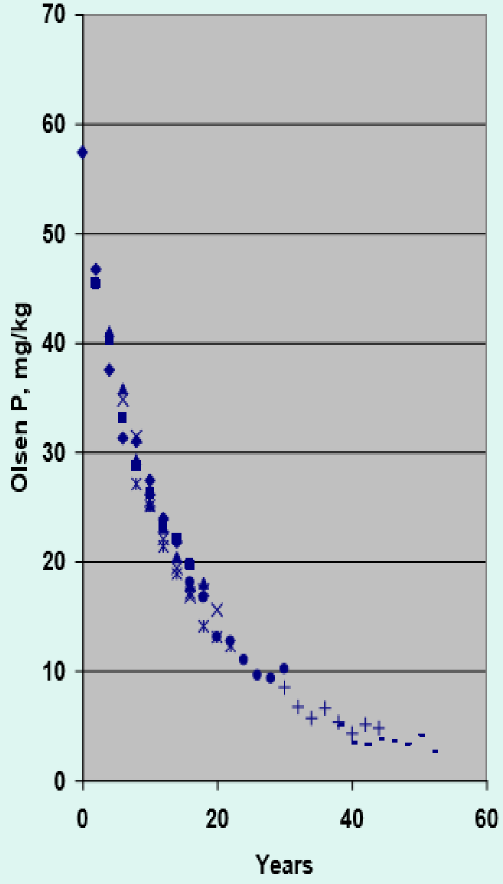


Fig. 5. Soil test phosphorus as affected by annual applications of commercial fertilizer.

6.5. SOIL P

Saxmundham: decline in Olsen P, unified decay curve



No fertilizer P added after 1968

"Half-life" of about 10 years

6.5. SOIL P

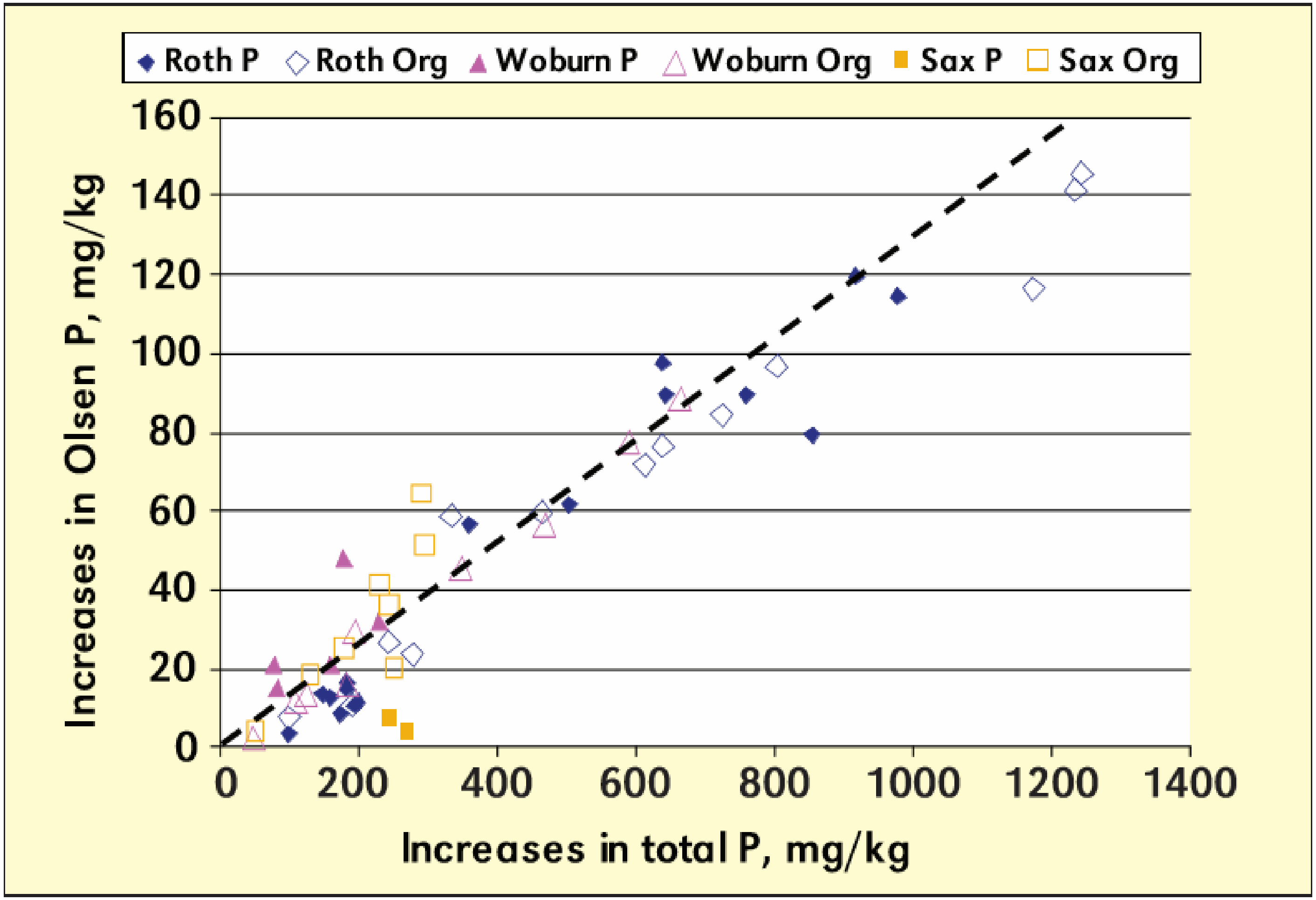
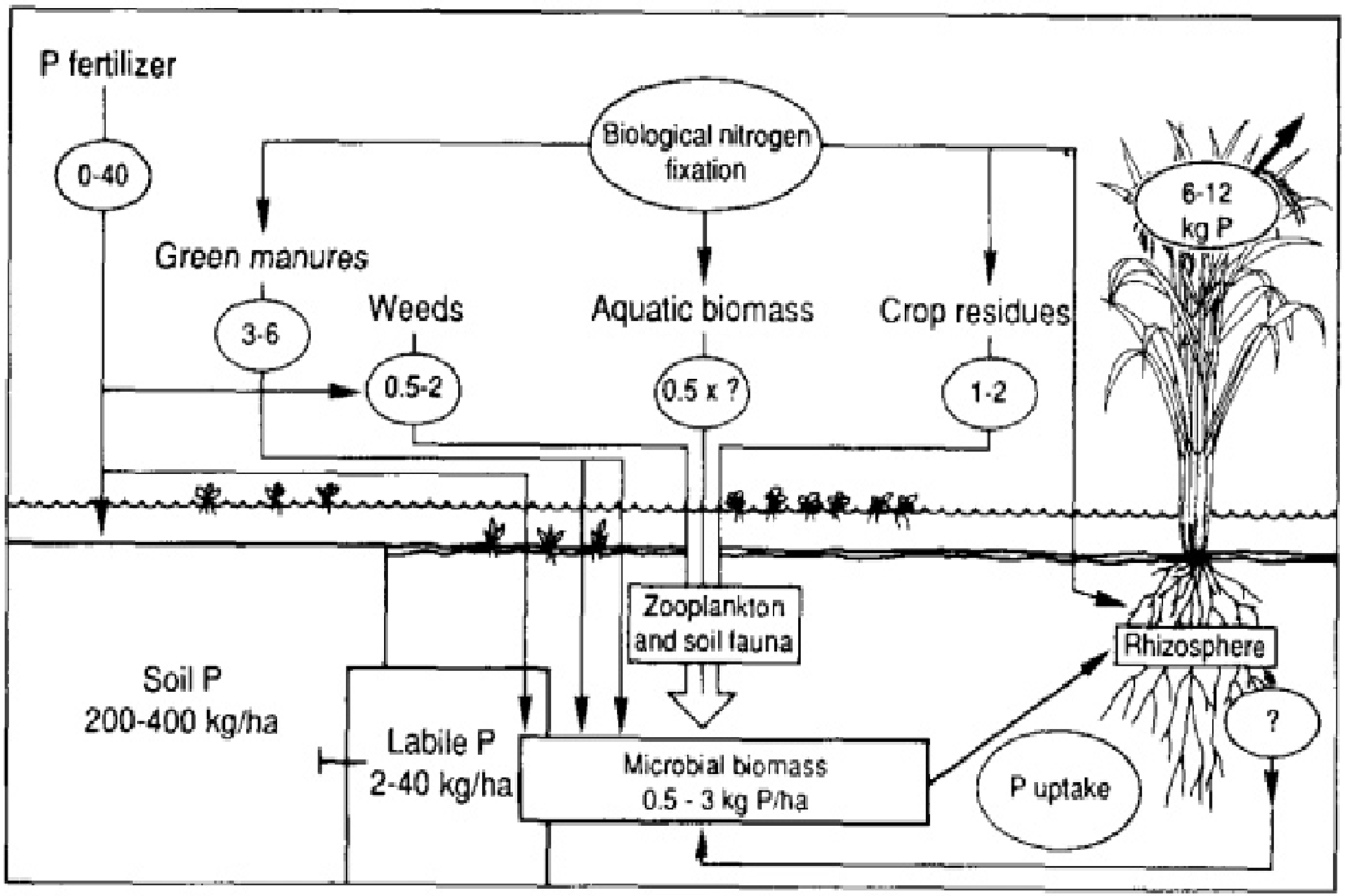


Figure 2. Relationship between total P and Olsen P.

(Dashed line represents 13% of added P remaining as Olsen P.)

6.5. SOIL P



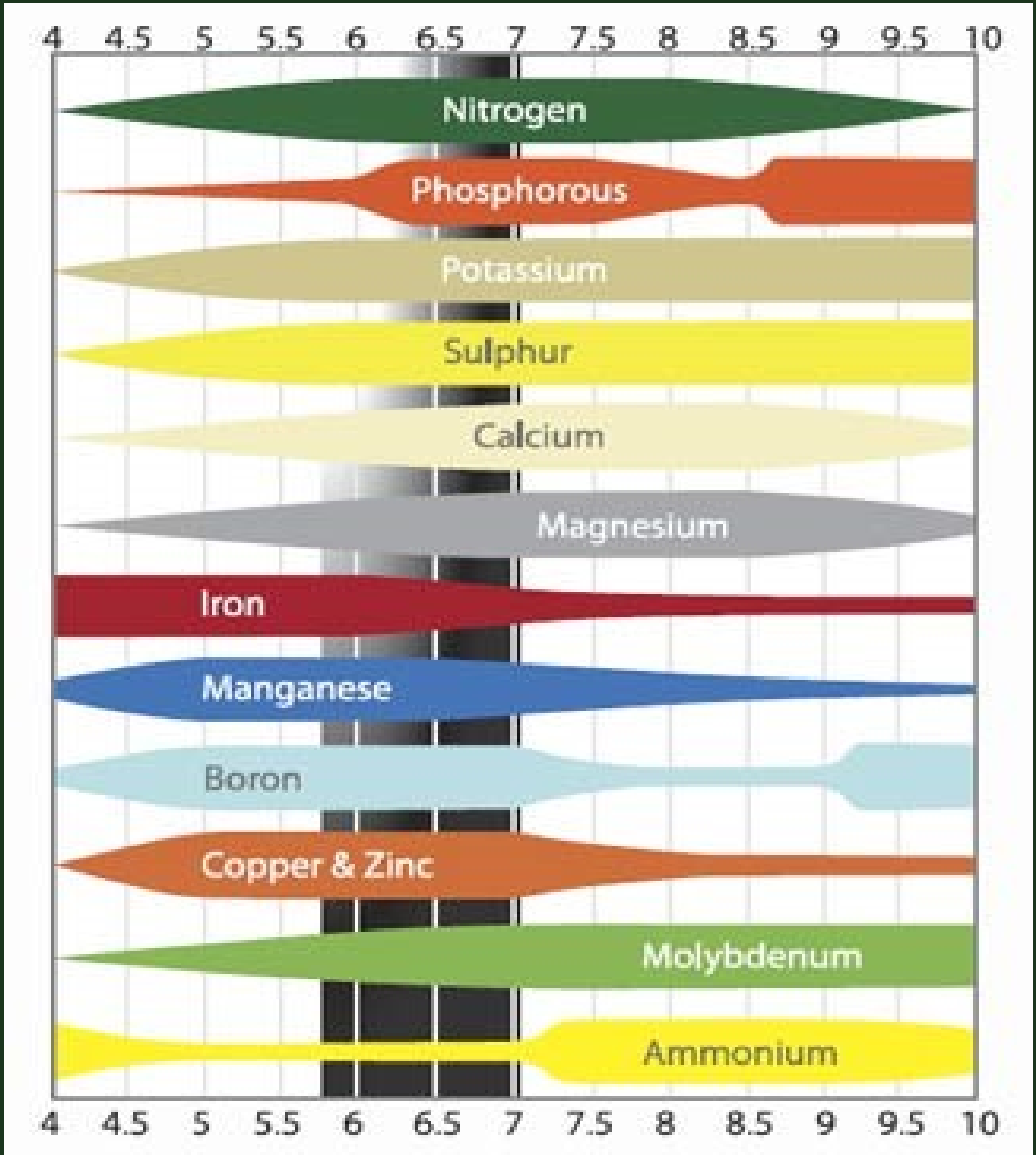
2. P pools and transformations in lowland ricefields.

5.6. SOIL P AVAILABILITY

5.6.2 Factors affecting Soil P availability

- Soil pH
- Organic matter decomposition & mineralisation
  a. OM quality
  b. Decomposer
  c. Environment
- Mineralisation & immobilization

Soil pH



4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10
Nitrogen
Phosphorous
Potassium
Sulphur
Calcium
Magnesium
Iron
Manganese
Boron
Copper & Zinc
Molybdenum
Ammonium
4 4.5 5 5.5 6 6.5 7 7.5 8 8.5 9 9.5 10

Soil pH

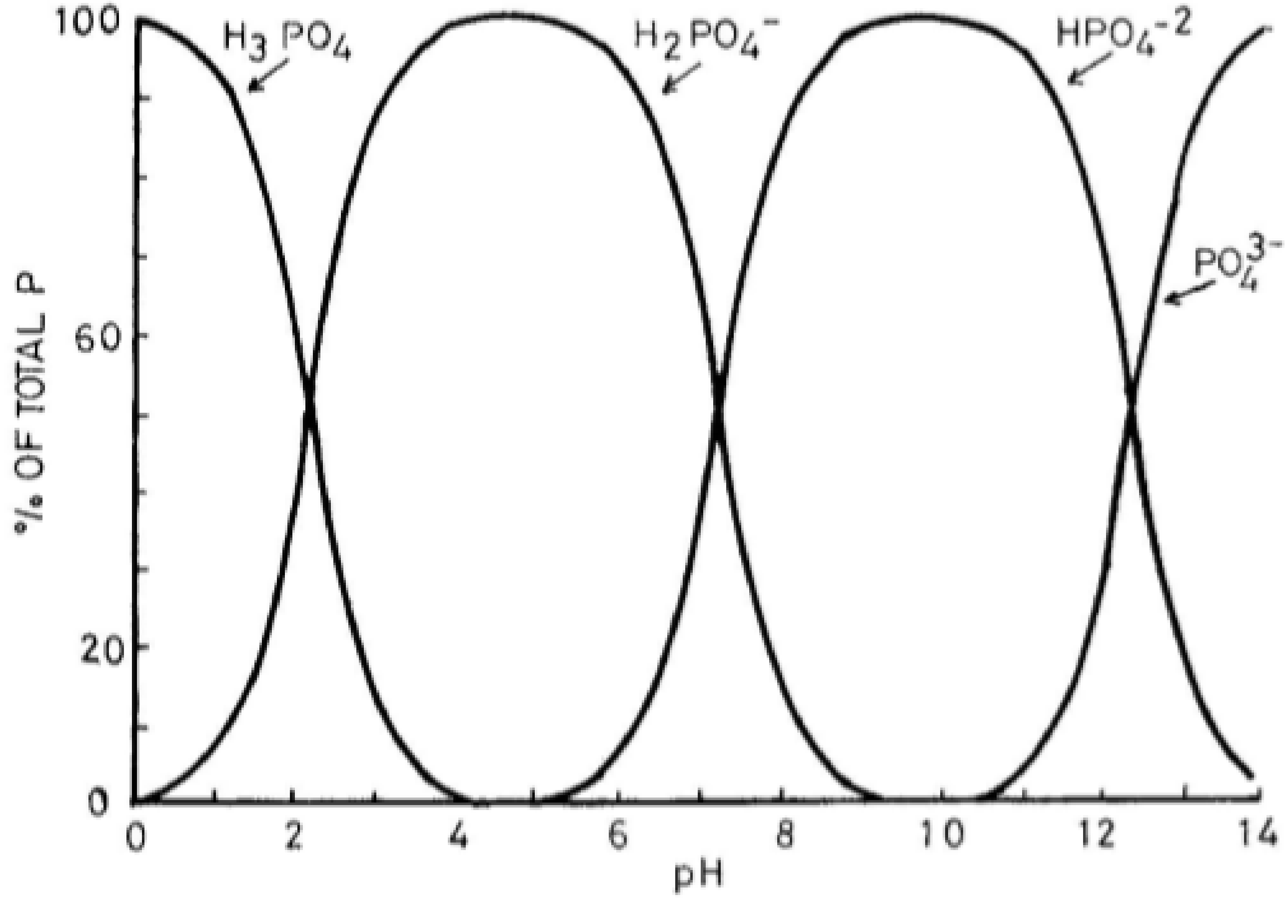
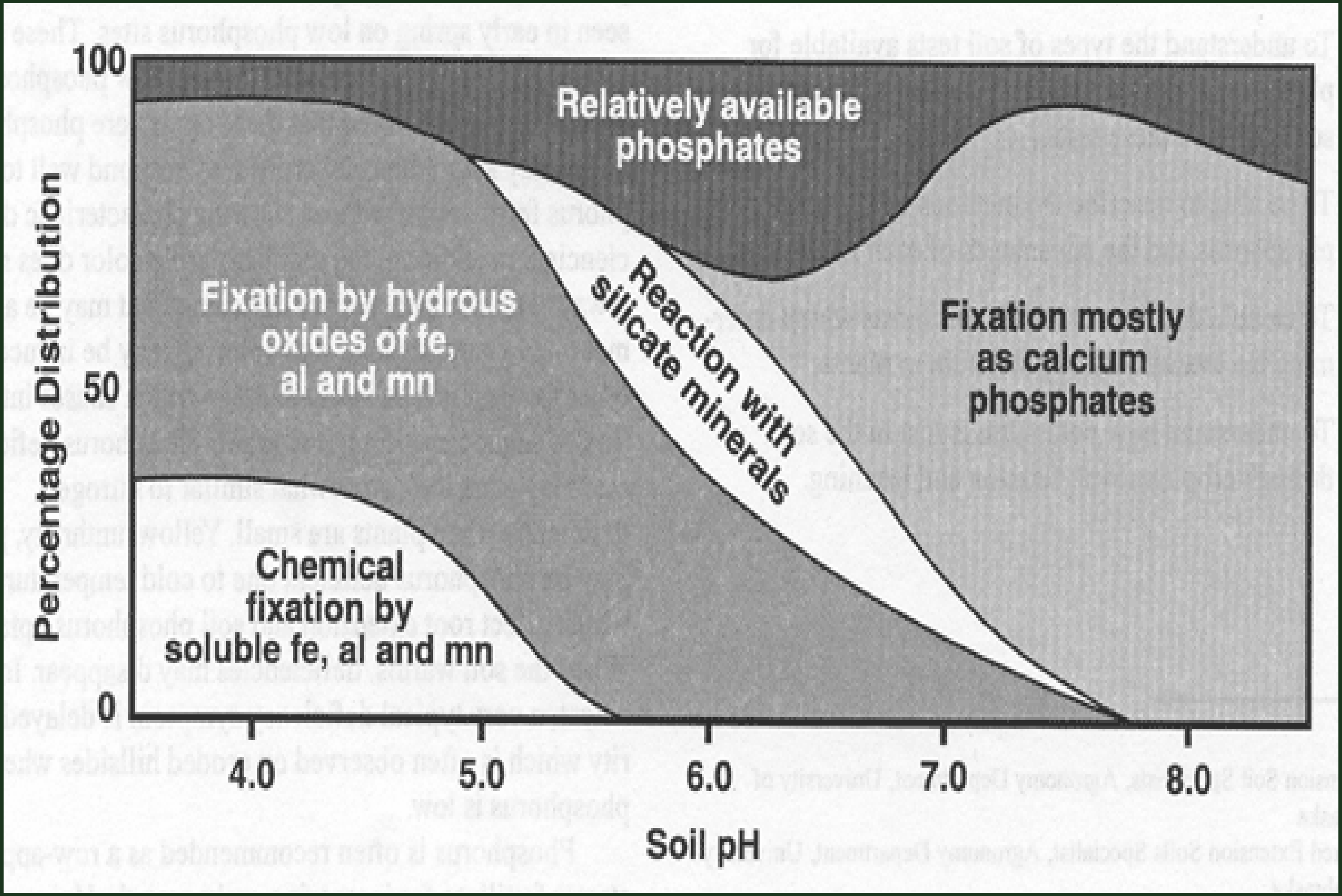


Figure 9.3. Distribution of orthophosphate species in solution as a function of pH.

Soil pH


100
50
0
Percentage Distribution
Relatively available phosphates
Fixation by hydrous oxides of fe, al and mn
Reaction with silicate minerals
Fixation mostly as calcium phosphates
Chemical fixation by soluble fe, al and mn
4.0
5.0
6.0
7.0
8.0
Soil pH

OM DECOMPOSITION & MINERALISATION

- Organic matter decomposition & mineralisation determine by:

  a. OM quality

  b. Decomposer

  c. Environment

5.5. AGRONOMIC ROLE OF P

5.5.1 Effect of P on growth and production

- P required for formation of ADP, ATP, DNA and RNA,, etc.
- P is a vital nutrient for root growth

5.5. AGRONOMIC ROLE OF P

5.5.1 Effect of P on growth and production

Table 9.4 Effect of Lime on Seed Yield (kg ha^{-1}) of Common Bean (*Phaseolus vulgaris* L.) Grown at Different P Rates in an Oxisol in Central Brazil

P level (kg ha^{-1})	Without lime	With lime
0	37	110
26	777	900
52	953	1207
104	1427	1380
208	1323	1363

From Fageria et al. 1990. *Crops and Enhancers of Nutrient Use*, Baligar, V.C. and Duncan, R.R., Eds., p. 675. With permission of Academic Press.

5.5. AGRONOMIC ROLE OF P

5.5.1 Effect of P on growth and production

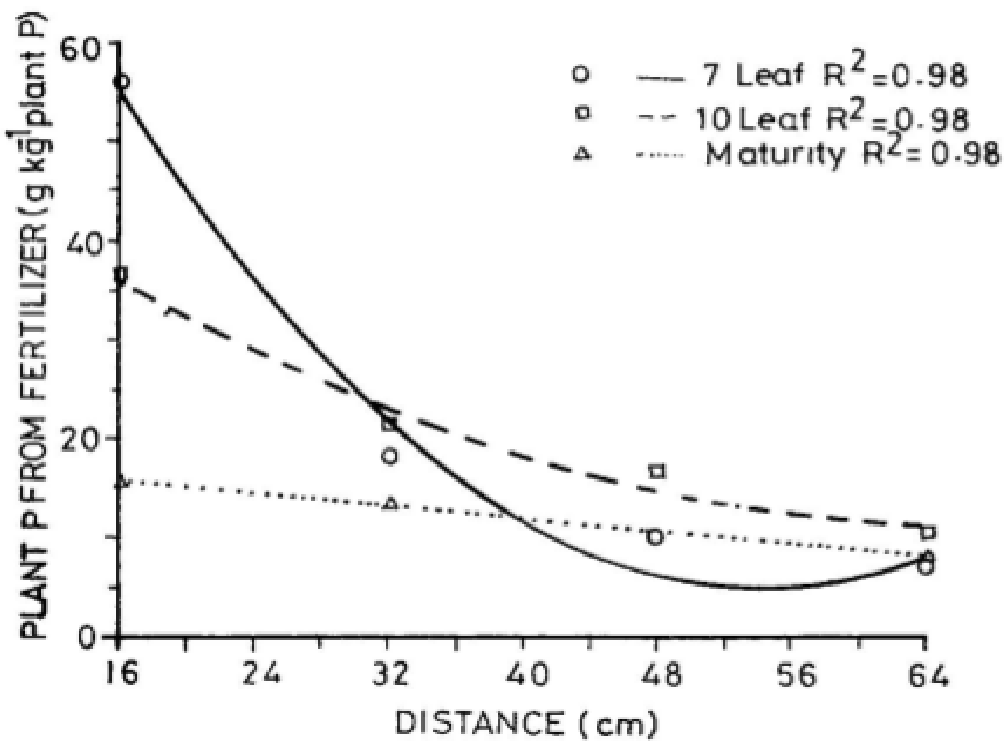


Figure 9.11. Effect of P distance from plants on P uptake from fertilizer at three sampling times over 2 years, 1984 and 1985. (From Eghball and Sander. 1989. Soil Sci. Soc. Am. J. 53:282–287. With permission of SSSA.)

5.5. AGRONOMIC ROLE OF P

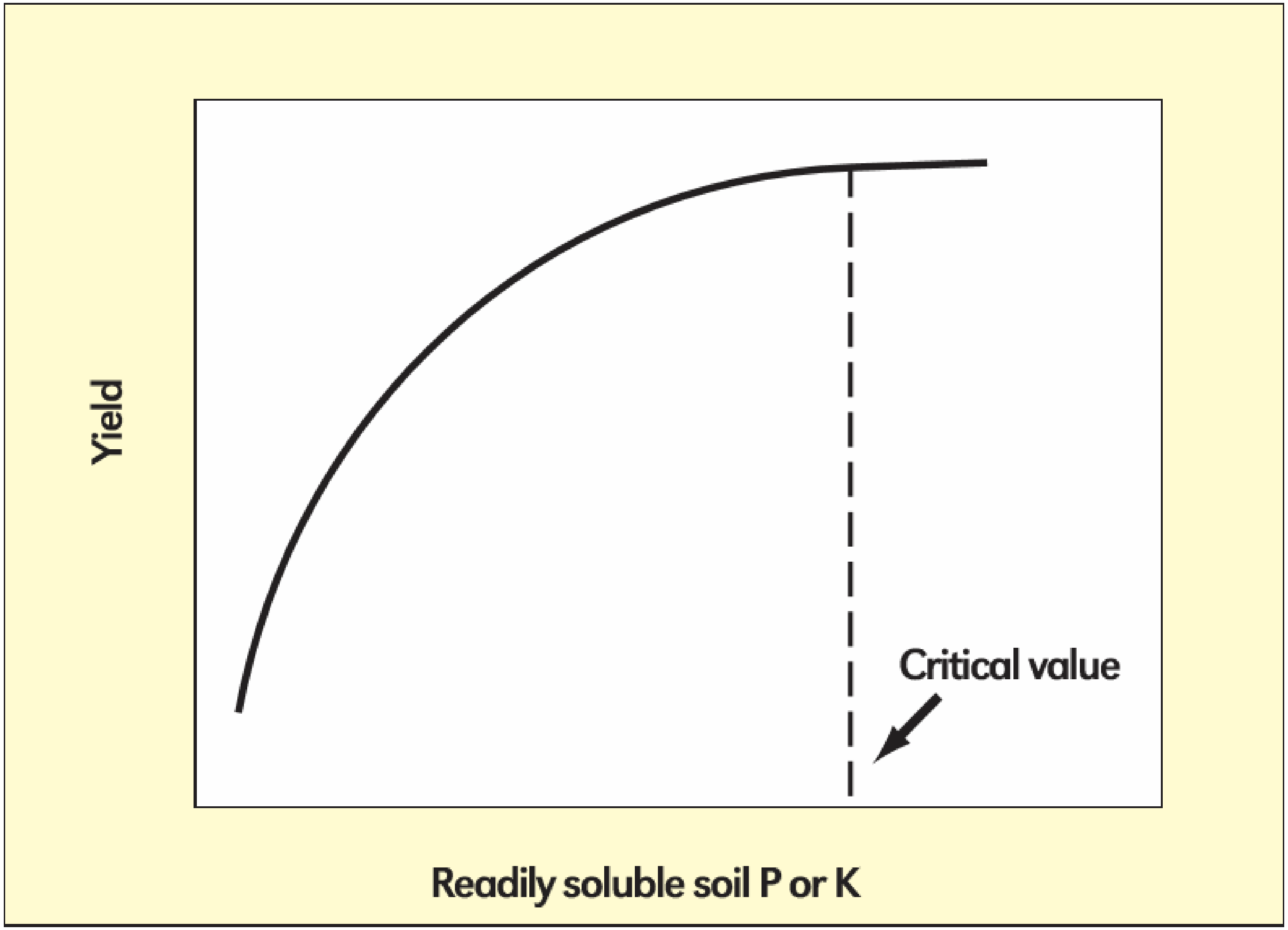


Figure 3. How much P should there be in the readily available pool?

5.5. AGRONOMIC ROLE OF P

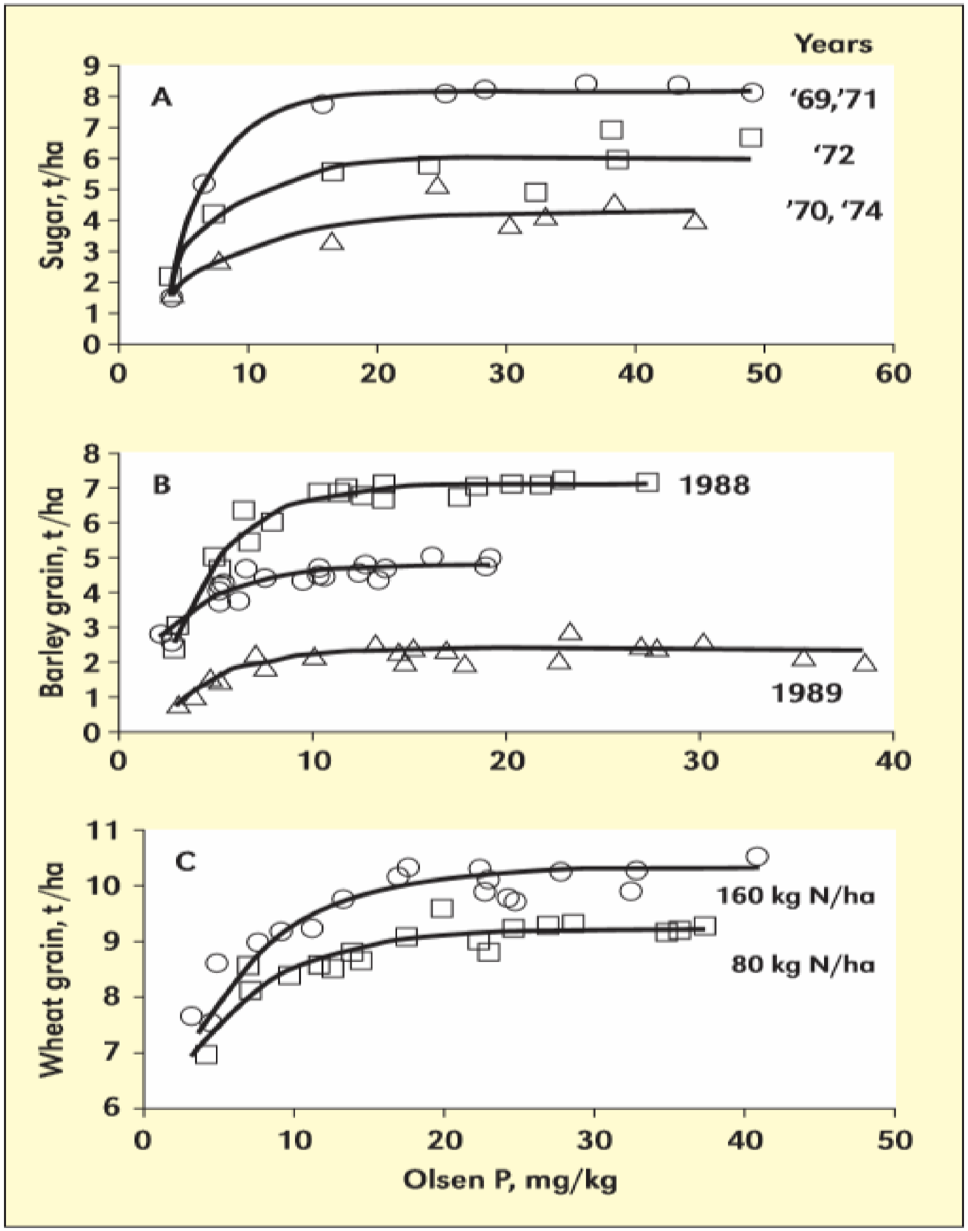
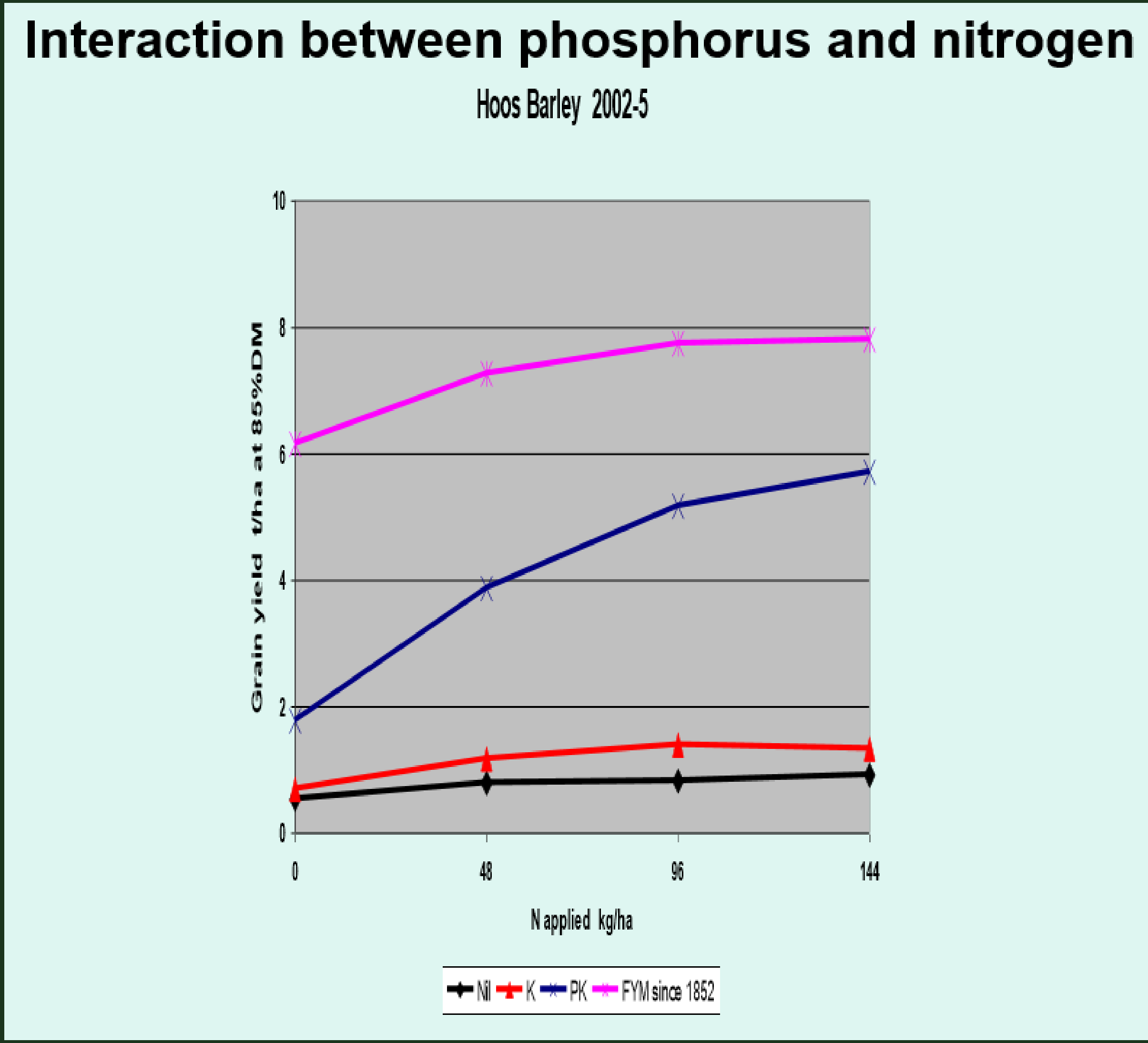


Figure 4. Example of critical values for arable crops.

5.5. AGRONOMIC ROLE OF P

5.5.1 Effect of P on growth and production



P Deficiency Symptom

- Purplish leaf, especialy in the margin

5.5. AGRONOMIC ROLE OF P

6.5.2 P deficiency simptoms

Gejala Defisiensi P

Ketapang

Tomato

Corn

6. PHOSPHORUS MANAGEMENT

6.1 Decreasing P Losses

6.2 Increasing P uptake

6.3 Organic matter management

6.4. Management of P fertilization

6. PHOSPHORUS VS ENVIRO

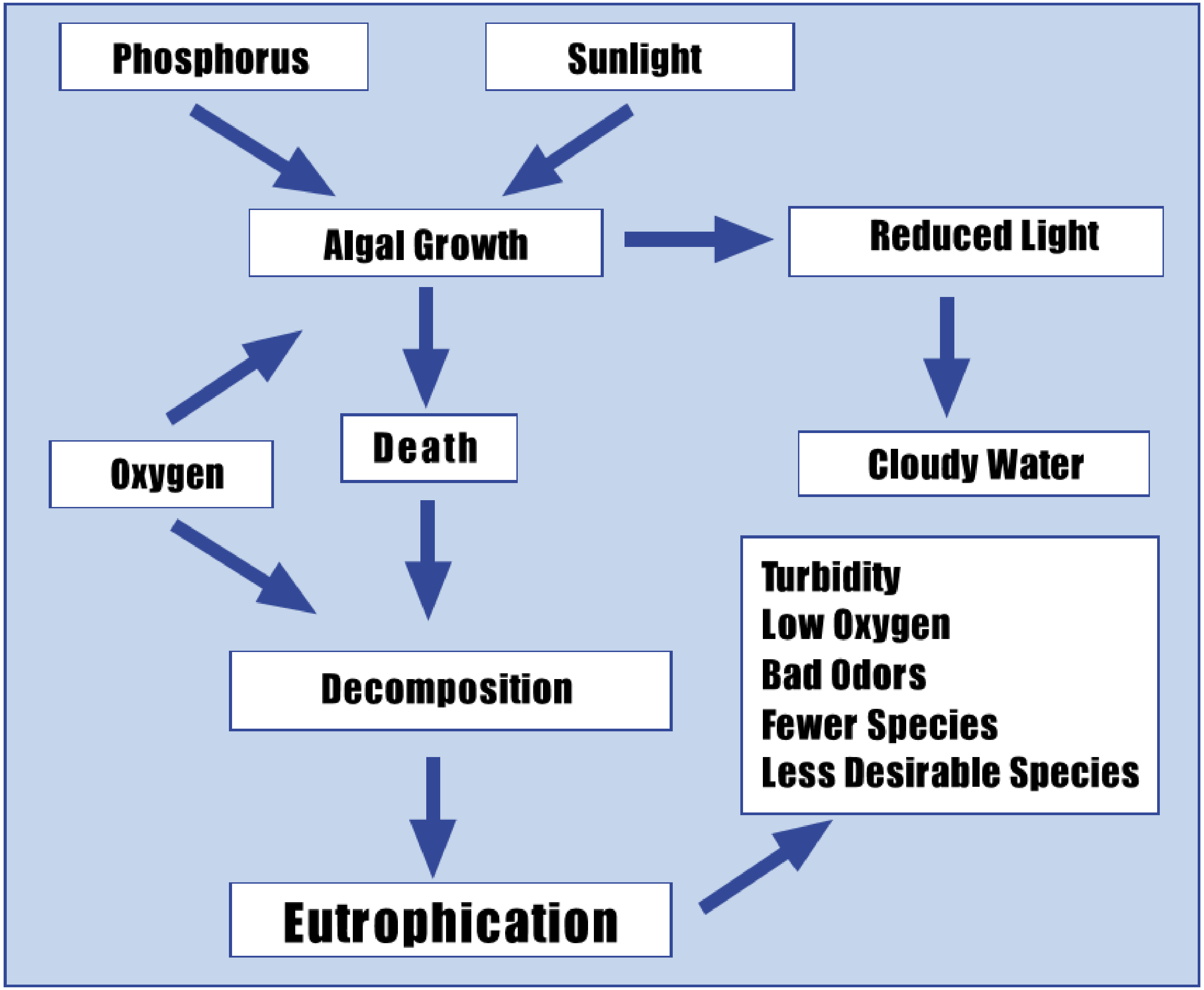


Figure 1. Effect of Phosphorus on Eutrophication

6. PHOSPHORUS MANAGEMENT

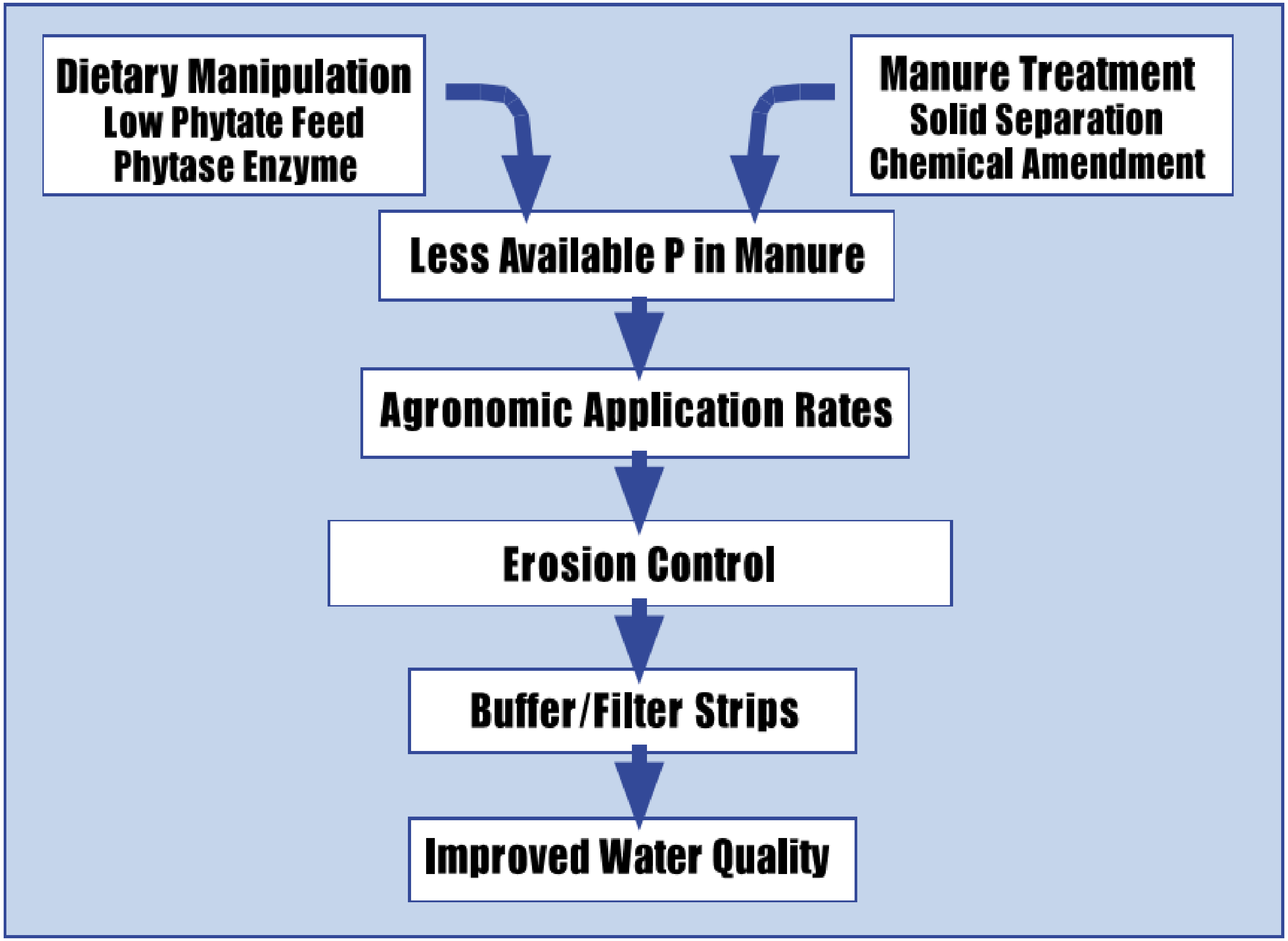


Figure 2. Best Management Practices for Manure Phosphorus Management

6. PHOSPHORUS MANAGEMENT

6.1 Decreasing P Losses

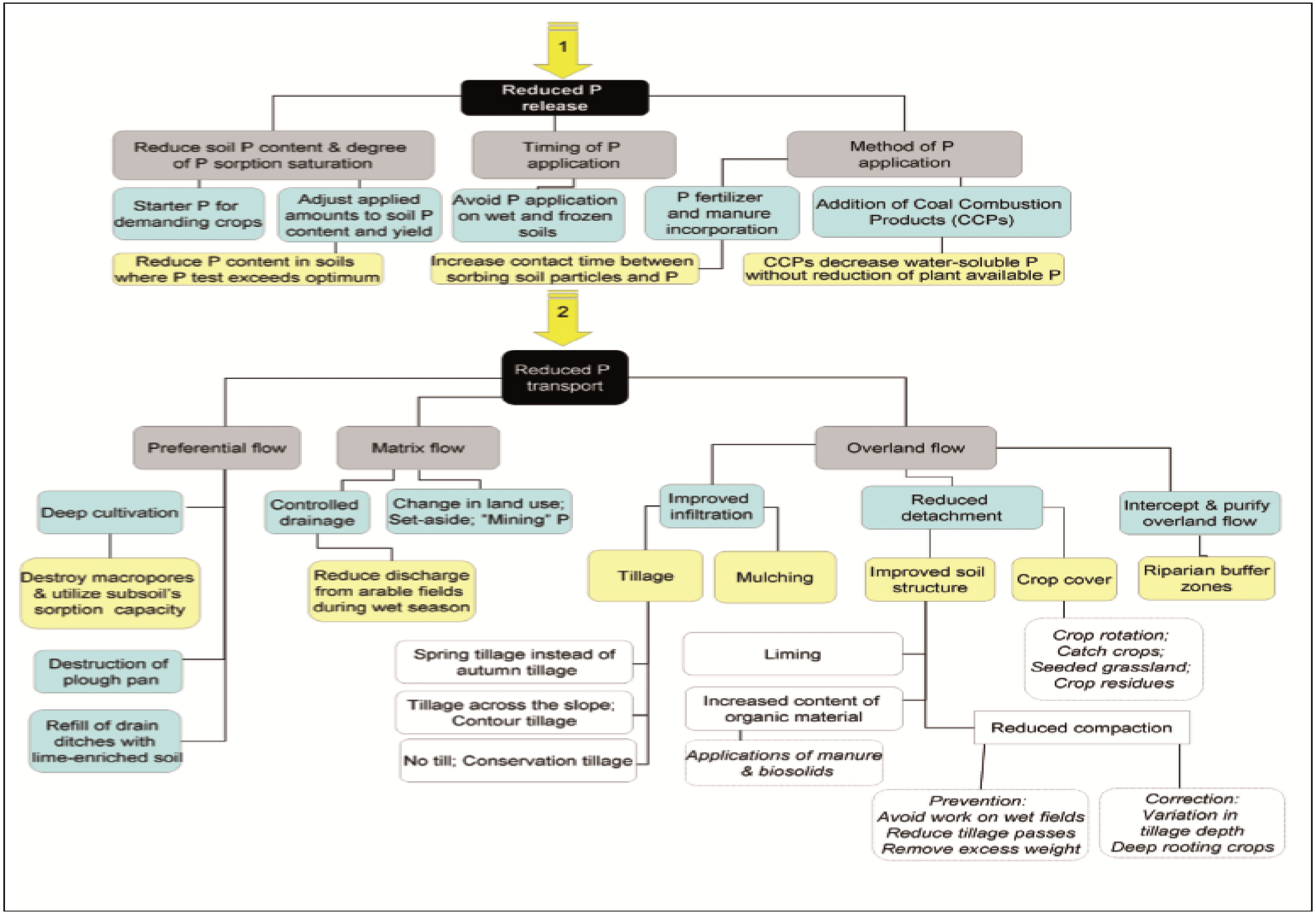


Figure 9.6. Flow diagram showing the relationships between measures for decreasing phosphorus losses from agriculture (Djodjic et al., 2005).

7. PHOSPHORUS MANAGEMENT VS environmental impac

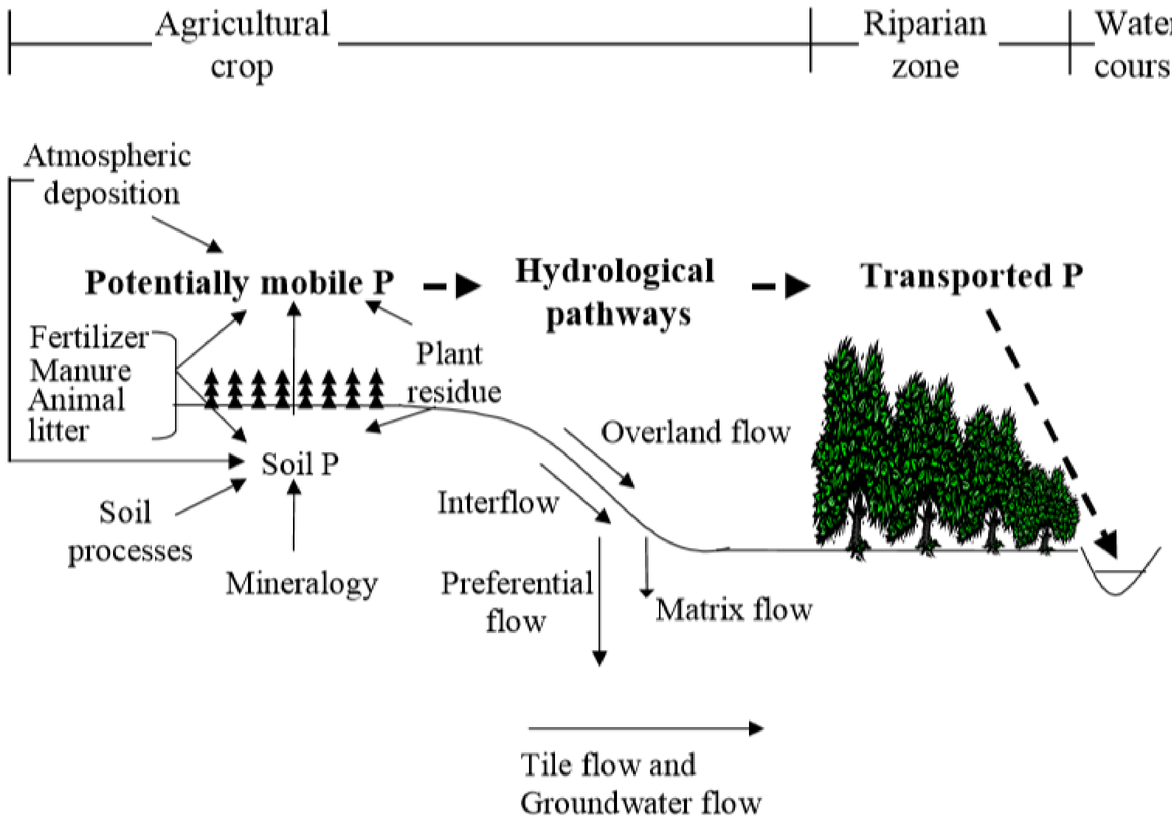


Figure 2. Potentially mobile agricultural P inputs and the hydrologic pathways that transport P to reach surface waters.

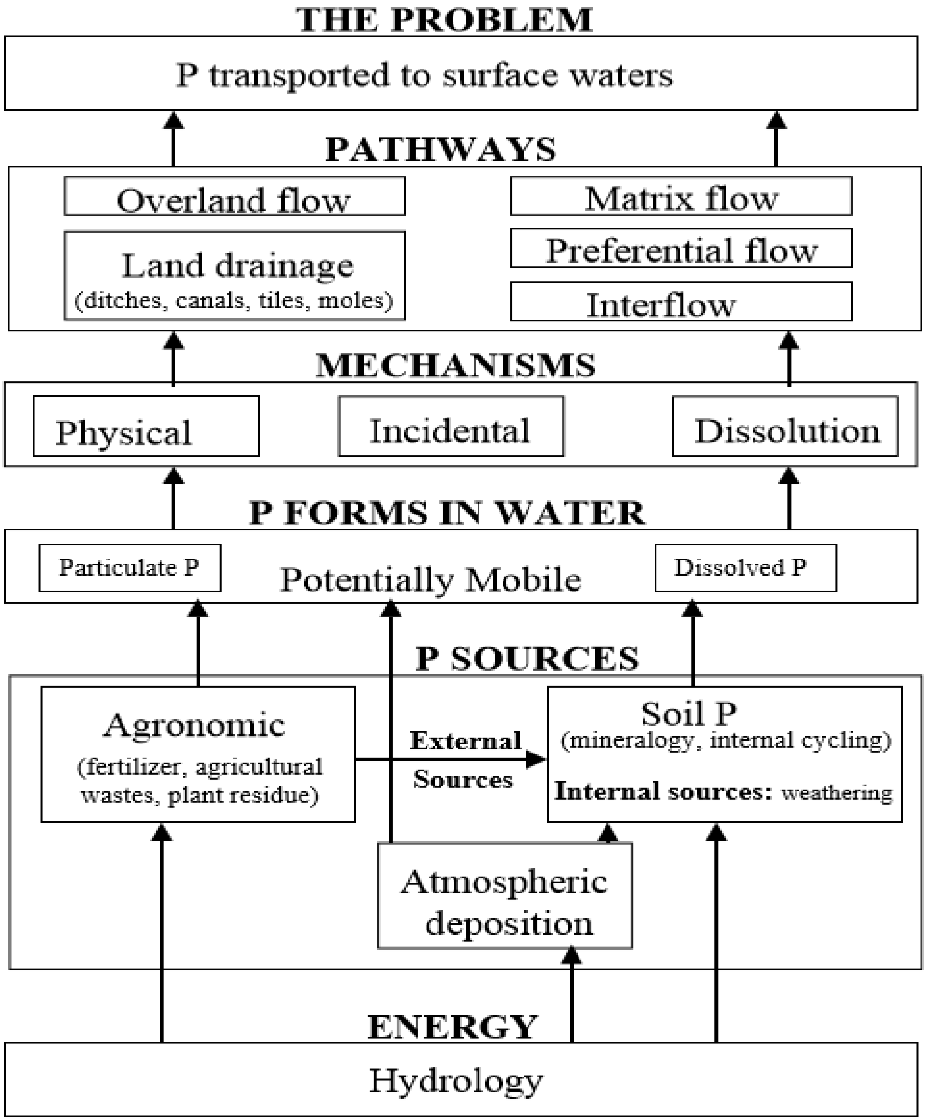


Figure 3. A model describing how NPS P reaches surface waters from terrestrial sources (modified from Haygarth and Sharpley, 2000). Hydrology provides the energy for P transport and the soil, atmospheric deposition, and agronomic practices, are the sources. Phosphorus transport is initiated by three mechanisms and P can reach the surface waters through one or more of these pathways.

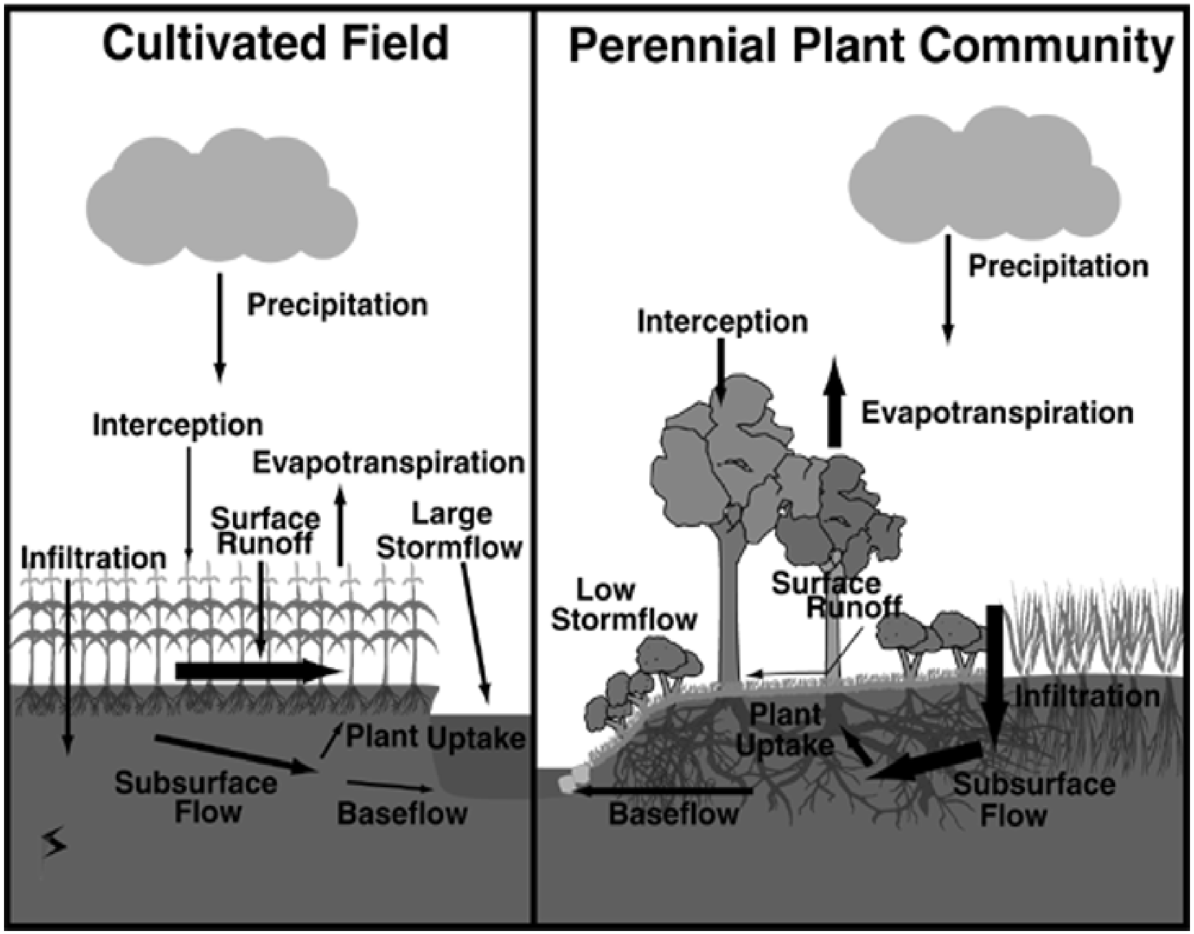


Figure 14. Nontilled row-cropped fields have more overland flow and less total evapotranspiration resulting in larger flow compared to riparian buffers that reduce stormflow and increase baseflow due to higher infiltration and evapotranspiration. Reducing overland flow and streambank erosion will decrease P losses (Schultz et al., 2000).

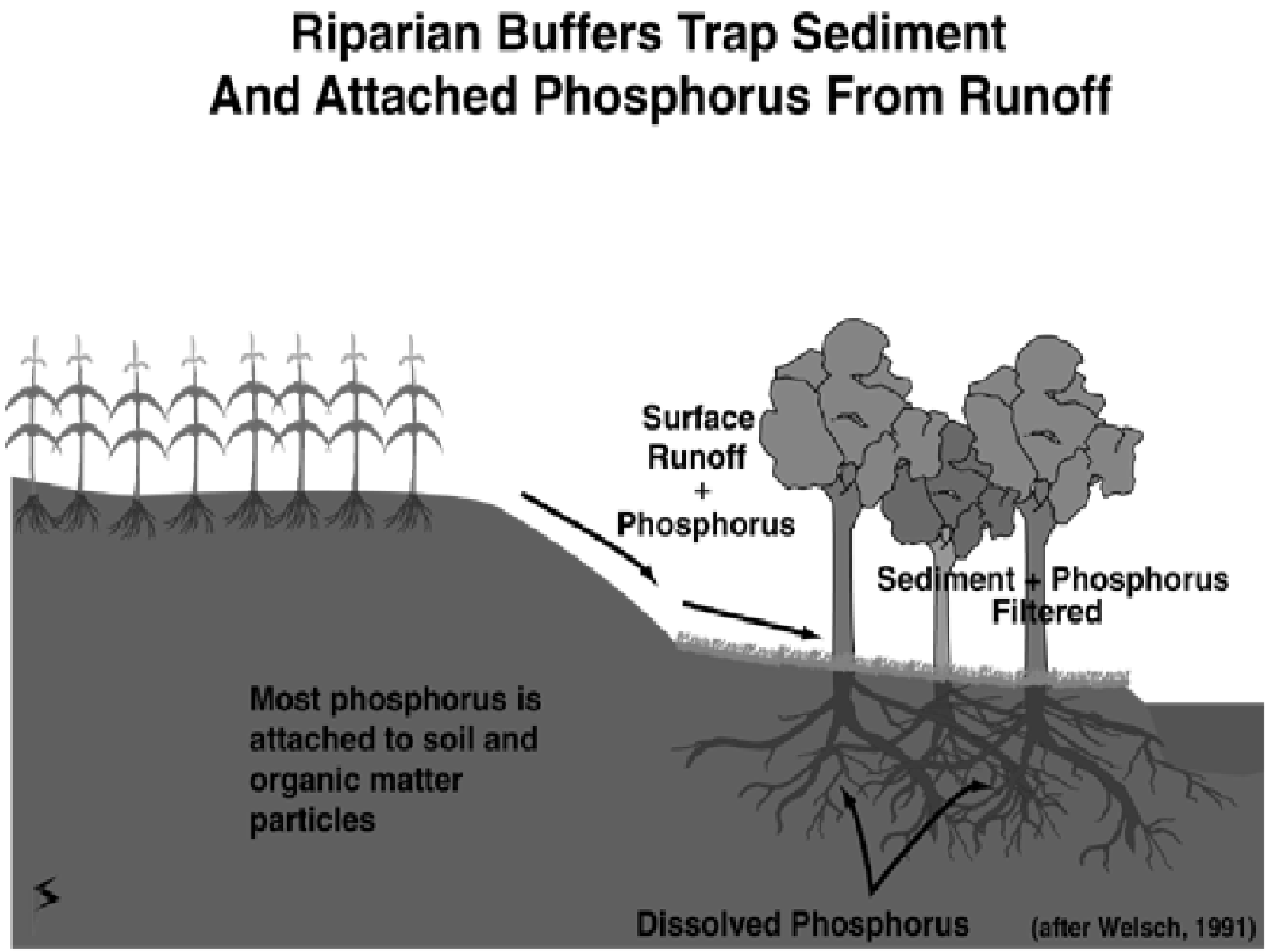


Figure 15. Phosphorus movement in riparian forest buffers. Sediment and TP (>0.45) are filtered from overland flow and TP (<0.45) can be taken up by biota of the living filter (Schultz et al., 2000).

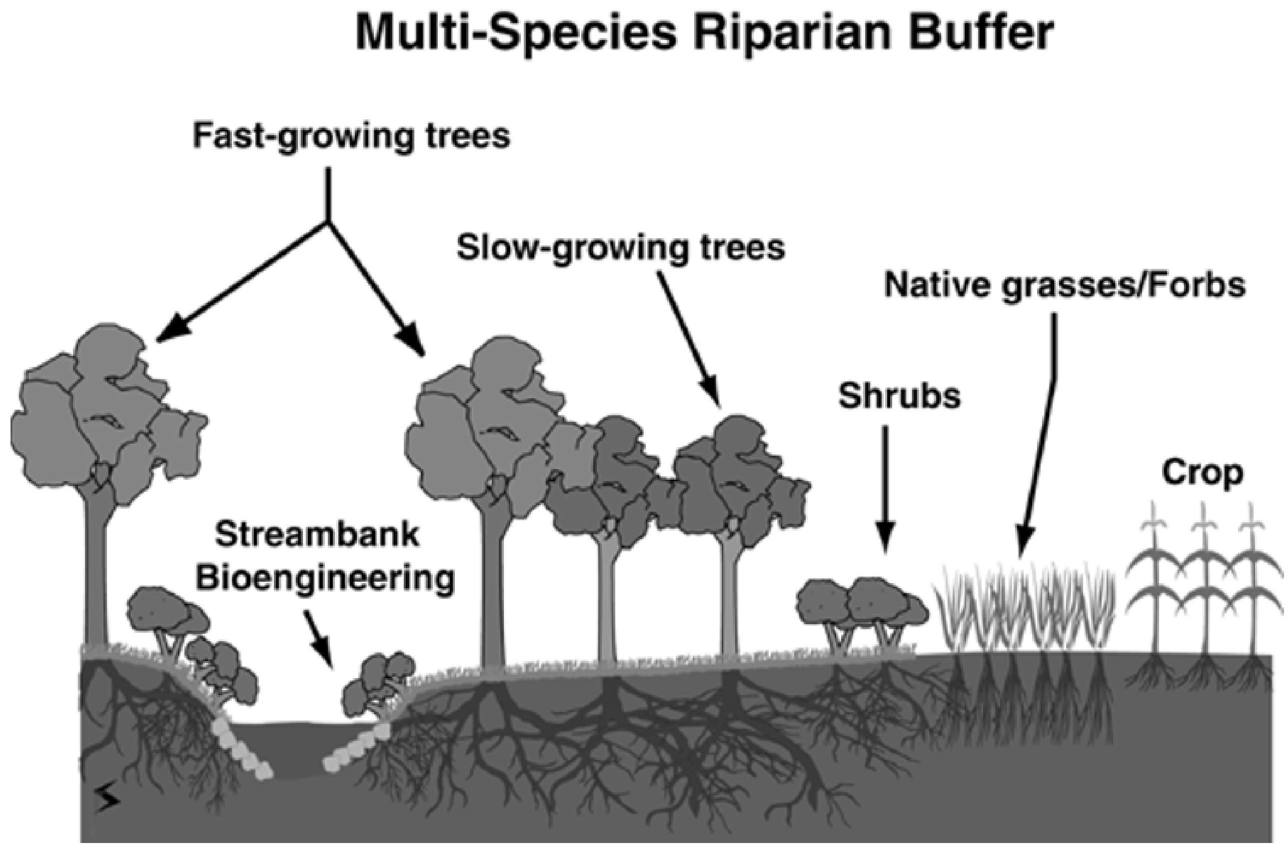


Figure 17. The multi-species riparian buffer model. The first zone, is located along consists of a managed tress and shrubs. They provide bank stability, wildlife habitat, are a nutrient and sediment sink, and modify the aquatic environment. The second zone, consist of native grass and forbs that intercept overland flow, increase infiltration and intercept NPS pollutants (Schultz et al., 2000).

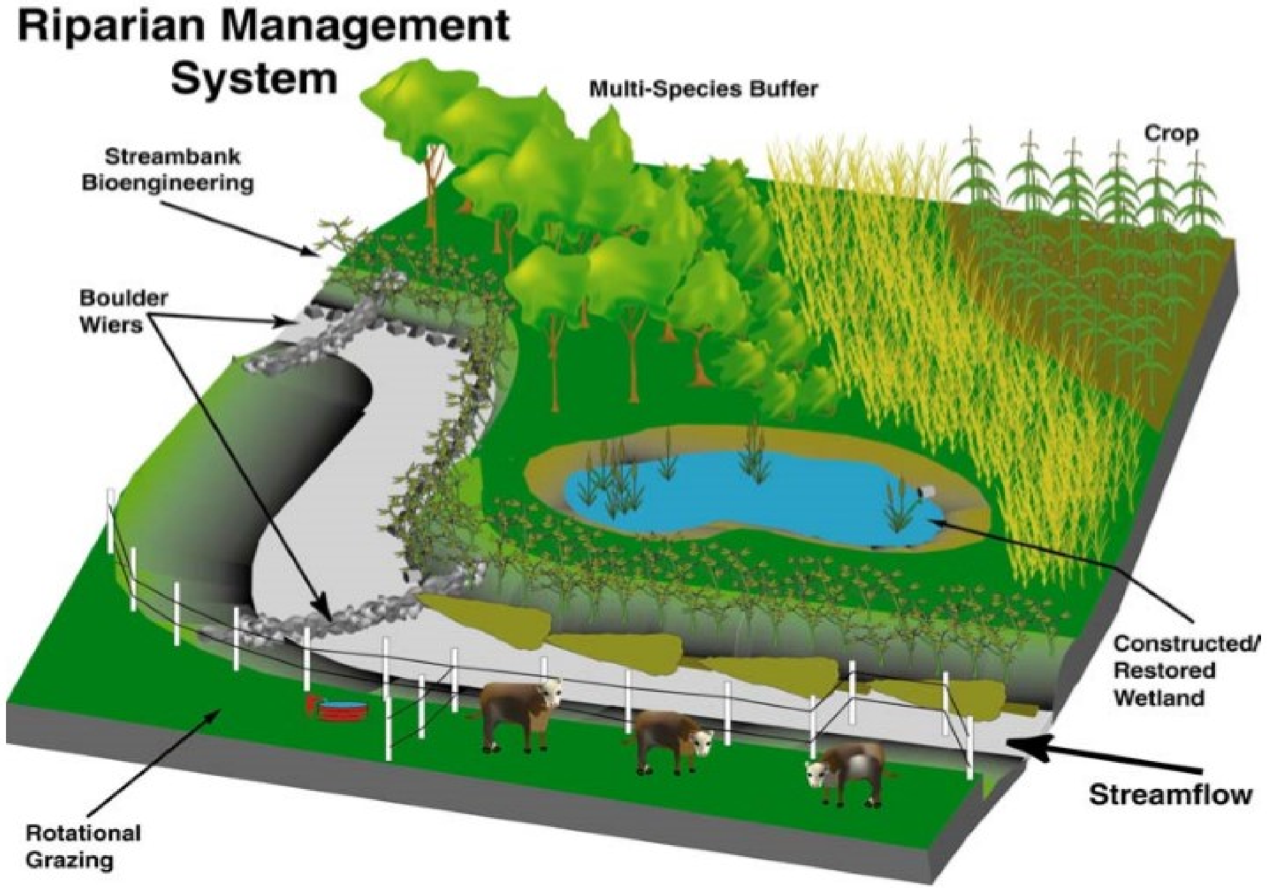


Figure 19. The Riparian Management System (RiMS) consists of five practices: i) multi-species riparian buffer with woody plants and warm-season grasses that intercept NPS from adjacent land practices, ii) streambank bioengineering that provide bank stability, iii) constructed-restored wetlands that intercept and filter NPS from subsurface tiles, iv) cool-season or warm-season grasses can replace MRB that may be used for rotational grazing with stream fenced out and v) instream structures like boulder weirs (Schultz et al., 2000).

Table 17. The transport and source characteristics with their respective weight factors, and the five P loss-rating levels of the watershed-modified P-index system. The transport characteristics include soil erosion, soil runoff class and return period/distance. The source characteristics include soil P test, P fertilizer rate, P fertilizer application method, organic P application rate, and organic P application method. [a]

TRANSPORT CHARACTERISTIC (Weight Factor)	**PHOSPHORUS LOSS RATING** (VALUE)				
	None (0.6)	**Low** (0.7)	**Medium** (0.8)	**High** (0.9)	**Very High** (1)
Soil Erosion (1.5)	N/A	< 10 Mg ha^{-1}	10-20 Mg ha^{-1}	20-30 Mg ha^{-1}	> 30 Mg ha^{-1}
Soil Runoff Class (0.5)	N/A	Very Low or Low	Medium	High	Very High
	None (0.2)	**Low** (0.4)	**Medium** (0.6)	**High** (0.8)	**Very High** (1)
Return period/distance (1.0)	> 10 yr > 170 m	6-10 yr 130-170 m	3-5 yr 80-130 m	1-2 yr 30-80 m	< 1 yr < 30 m

SOURCE CHARACTERISTICS (Weighing Factor)	**PHOSPHORUS LOSS RATING** (VALUE)				
	None (0)	**Low** (1)	**Medium** (2)	**High** (4)	**Very High** (5)
Soil Test P (1.0)	N/A	Low	Medium	High	Excessive
P Fertilizer Rate (kg P ha^{-1}) (0.75)	N/A	< 15	15-45	56-75	> 75
P Fertilizer Application Method (0.5)	N/A	Placed with planter deeper than 5 cm	Incorporate immediately before crop	Incorporate > 3 months before crop or surface applied > 3 months before crop	Surface applied > 3 months before crop
Organic P Source Application Rate (kg P ha^{-1}) (1.0)	N/A	< 15	15-45	56-75	> 75
Organic P Source Application Method (1.0)	N/A	Injected deeper than 5 cm	Incorporate immediately before crop	Incorporate > 3 months before crop or surface applied > 3 moths before crop	Surface applied to pasture > 3 months before crop

[a] Gburek et al. (2000).