Table 1 Forms of absorption and functions of essential nutrients in plants

Nutrient	*Forms taken up by plants*	*Functions*
Carbon	CO_2	Basic molecular component of carbohydrates, proteins, lipids, and nucleic acids
Hydrogen	H_2O	Hydrogen plays a central role in plant metabolism. Important in ionic balance and as main reducing agent; plays a key role in energy relations of cells
Oxygen	H_2O, O_2	Oxygen is like carbon in that it occurs in virtually all organic compounds of living organisms
Nitrogen	NH_4^+, NO_3^-	Nitrogen is a component of many important organic compounds ranging from proteins to nucleic acids
Phosphorus	$H_2PO_4^-$, HPO_4^{2-}	Central role in plants in energy transfer and protein metabolism
Potassium	K^+	Helps in osmotic and ionic regulation. Functions as a cofactor or activator for many enzymes of carbohydrate and protein metabolism
Calcium	Ca^{2+}	Calcium is involved in cell division and plays a major role in the maintenance of membrane integrity
Magnesium	Mg^{2+}	Component of chlorophyll and a cofactor for many enzymatic reactions
Sulfur	SO_4^{2-}	Sulfur is like phosphorus in that it is involved in plant cell energetic reactions
Iron	Fe^{2+}, Fe^{3+}	An essential component of many heme and nonheme Fe enzymes and carriers, including the cytochromes (respiratory electron carriers) and the ferredoxins. The latter are involved in key metabolic functions such as N fixation, photosynthesis, and electron transfer
Zinc	Zn^{2+}	Essential component of several dehydrogenases, proteinases, and peptidases, including carbonic anhydrase, alcohol dehydrogenase, glutamic dehydrogenase, and malic dehydrogenase
Manganese	Mn^{2+}	Involved in the O_2-evolving system of photosynthesis; is a component of the enzymes arginase and phosphotransferase
Copper	Cu^{2+}	Constituent of a number of important oxidase enzymes, including cytochrome oxidase, ascorbic acid oxidase, and lactase, and important in photosynthesis, and protein and carbohydrate metabolism
Boron	$B(OH)_3^0$	Activates certain dehydrogenase enzymes, involved in carbohydrate metabolism, synthesis of cell wall components; is essential for cell division and development
Molybdenum	Mo	An essential component of nitrate reductase and N_2-fixation enzymes; is required for normal assimilation of N
Chlorine	Cl^-	Essential for photosynthesis and as an activator of enzymes, involved in splitting water, and functions in osmoregulation of plants growing on saline soils

Table 2 Soil conditions inducing nutrient deficiencies for crop plants

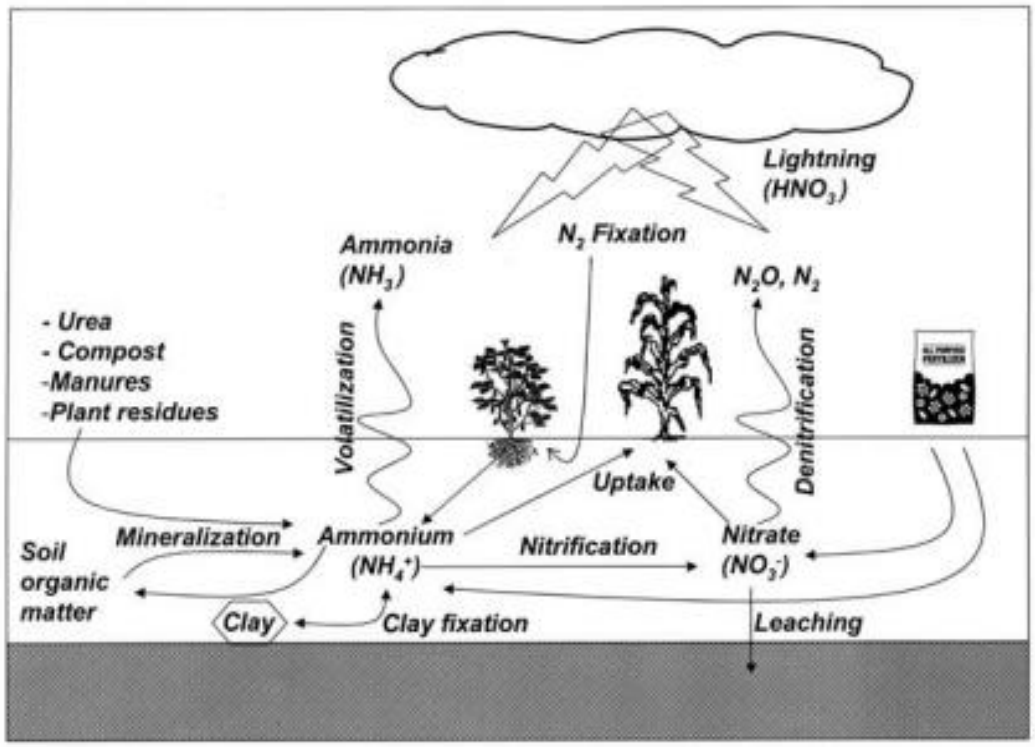
Nutrient	*Conditions inducing deficiency*
Nitrogen	Excess leaching with heavy rainfall; low organic matter content; burning the crop residue
Phosphorus	Acidic, organic, leached, and calcareous soils; high rate of liming
Potassium	Sandy, organic, leached, and eroded soils; high liming application, intensive cropping system
Calcium	Acidic, alkaline, or sodic soils
Magnesium	Acidic, alkaline, or sodic soils
Sulfur	Low organic matter content of soils; use of N and P fertilizers containing no sulfur; burning the crop residue
Iron	Calcareous soils; soils high in P, Mn, Cu, or Zn; high rate of liming
Zinc	Highly leached acidic soils; calcareous soils; high levels of Ca, Mg, and P
Manganese	High organic matter content; calcareous soils
Copper	Sandy soils; high liming rate in acid soils
Boron	Sandy soils; naturally acidic leached soils; alkaline soils with free lime
Molybdenum	High podzolized soils; well-drained calcareous soils

widely used separately or collectively as nutrient-availability, -deficiency or -sufficiency diagnostic aids. They are extremely helpful, yet are not without limitations.

Table 3 Nutrient-deficiency symptoms in field crops

Nutrient	*Symptoms*
N	Chlorosis starts in old leaves; in cereals tillering is reduced; under field conditions, if deficiency is severe, whole crop appears yellowish and growth is stunted
P	Growth is stunted; purple–orange color of older leaves; new leaves dark green; in cereals tillering is drastically reduced
K	Older leaves may show spots or marginal burn starting from tips; increased susceptibility to diseases, drought, and cold injury
Ca	New leaves become white; growing points die and curl
Mg	Marginal or interveinal chlorosis with pinkish color of older leaves; sometimes leaf-rolling, like drought effect; plants susceptible to winter injury
S	Chlorosis of younger leaves; under severe deficiency whole plant becomes chlorotic and similar to appearance in N deficiency
Zn	Rusting in strip of older leaves with chlorosis in fully matured leaves; leaf size is reduced
Fe	Interveinal chlorosis of younger leaves; under severe deficiency whole leaf becomes first yellow and finally white
Mn	Similar to iron deficiency; at advanced stage necrosis develops instead of white color
Cu	Chlorosis of young leaves, rolling, and dieback
Mo	Mottled pale appearance in young leaves; bleaching and withering of leaves
B	Pale green tips of blades, bronze tints; death of growing points

NITROGEN CYCLE



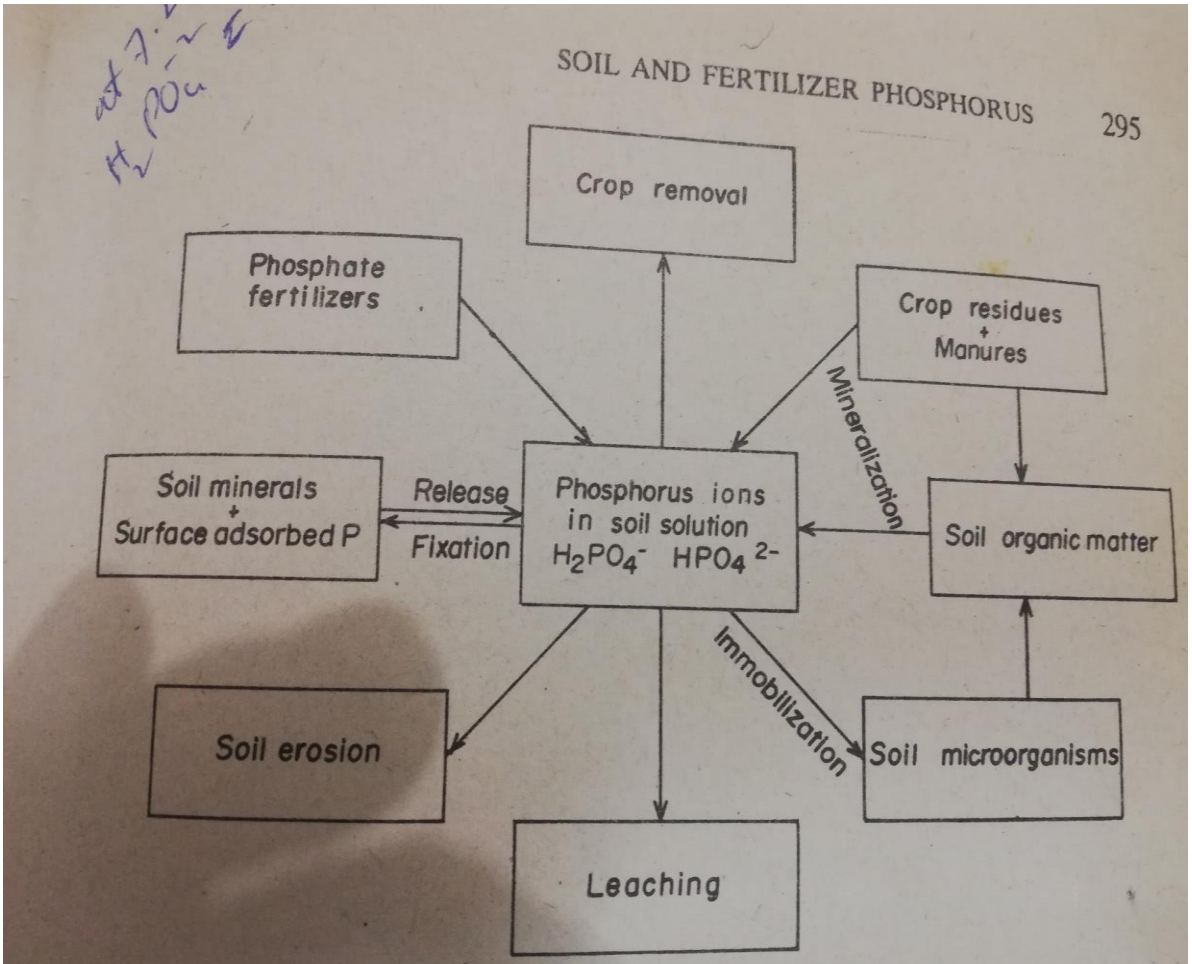


Figure 10.2 Phosphorus dynamics in the soil.