Characteristics And Properties Of Waterlogged Soils

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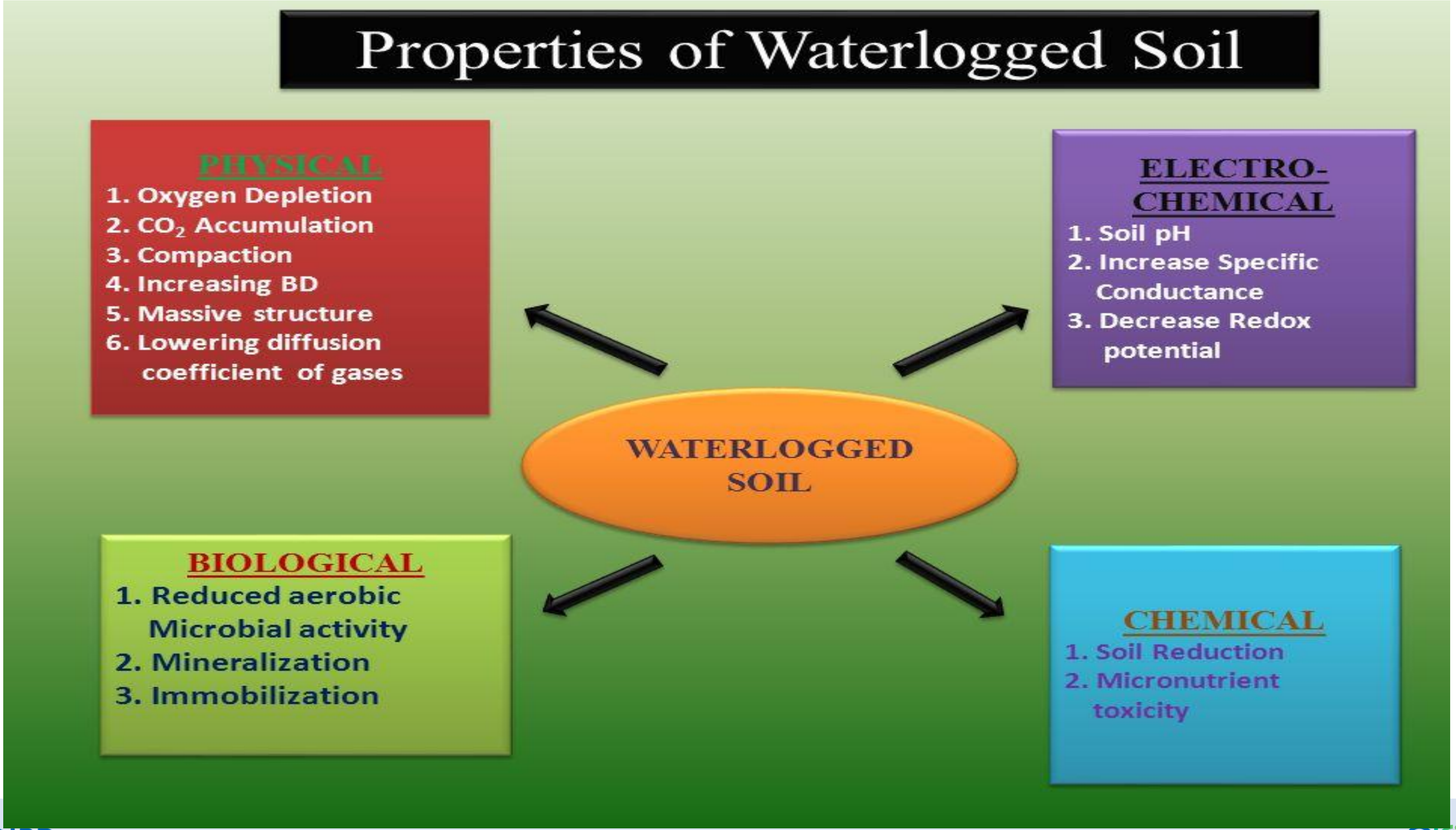
What is a submerged soil?

Soils that are saturated with water for a sufficiently long time annually give the soil distinctive gley horizons resulting from oxidation-reduction processes following changes in the soil profile

- Partially oxidized A horizon high in organic matter
- Mottled zone in which oxidation and reduction alternate
- Permanently reduced zone which is bluish green
- More amount of soil solution
- Reduced oxygen level and aerobic microbial activity
- Altered chemical status of the soil


Properties of Waterlogged Soil
PHYSICAL
1. Oxygen Depletion
2. CO_2 Accumulation
3. Compaction
4. Increasing BD
5. Massive structure
6. Lowering diffusion coefficient of gases
ELECTRO-CHEMICAL
1. Soil pH
2. Increase Specific Conductance
3. Decrease Redox potential
WATERLOGGED SOIL
BIOLOGICAL
1. Reduced aerobic Microbial activity
2. Mineralization
3. Immobilization
CHEMICAL
1. Soil Reduction
2. Micronutrient toxicity

Properties of Submerged Soil:

- Physical (Aeration status l, compaction, bulk density,water retention and transmission etc.),
- Chemical (soil reduction and transformation of different nutrient elements etc.),
- Electro-chemical (soil pH, specific conductance and redox potential etc.)
- Biological properties (decomposition of organic matter, mineralization, immobilization processes etc.)

Aeration status of the soil

- Soil submergence causes, water to replaces air in pore spaces
- Oxygen-diffusion in the water layer above the soil is very slow with high demand of O2
- Soil is practically devoid of oxygen.
- Soil gases like CO2 and methane (CH4) accumulate and also may escape as bubbles if pressure builds up

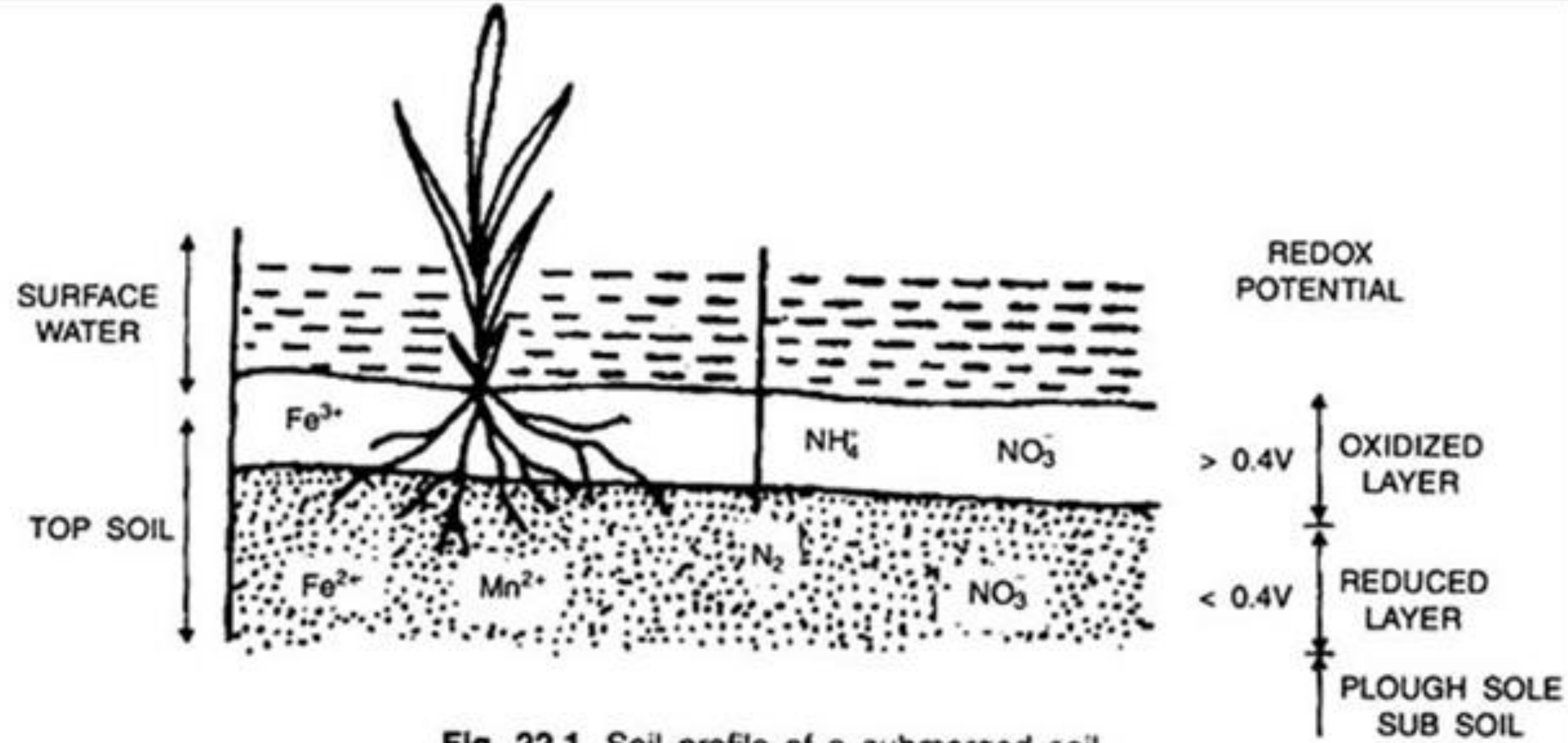


Fig. 22.1. Soil profile of a submerged soil.

Compaction

- Soil solids are re-arranged with compression of liquid and gaseous phases accompanied by volume change.
- Affects the water retention characteristics, water intake rates and gaseous exchange.
- In compacted soil, bulk density, micro-voids, thermal conductivity, diffusivity and nutrient mobility increases
- Macro-voids, hydraulic conductivity and water intake rates decrease

Bulk Density

- When soil is compacted to such a degree that all voids (pore spaces) are filled with water, no air voids (spaces) are present, and no soil water is expelled from the voids, the soil is saturated and its bulk density is maximum.

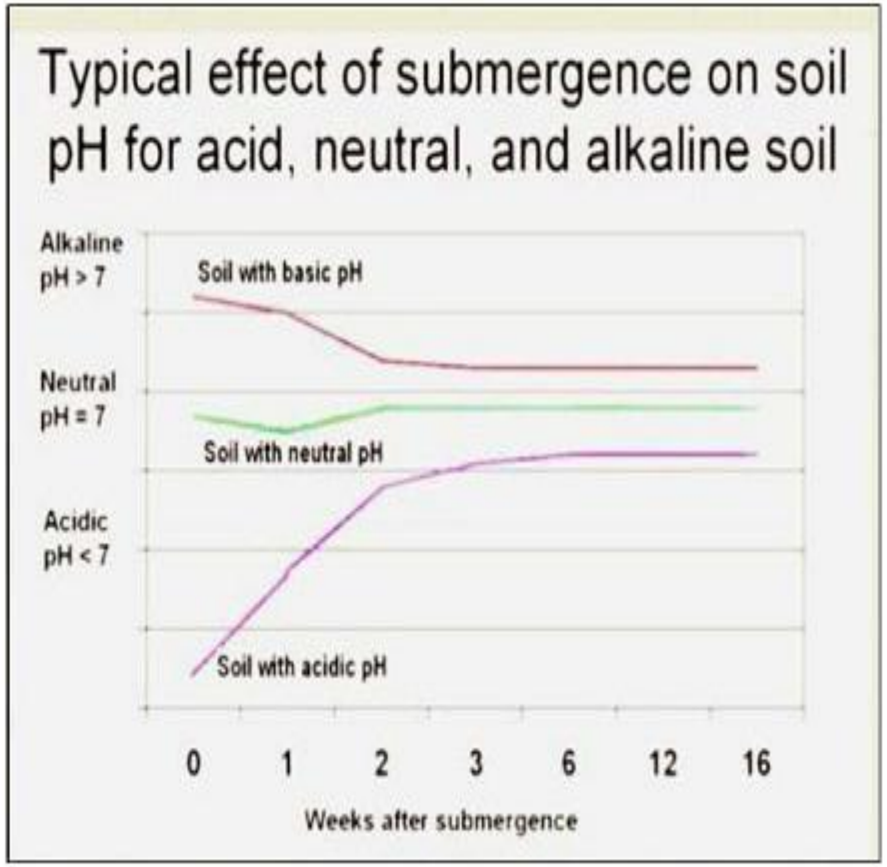
Electro-chemical Changes on submergence

- Decrease in redox potential (Eh) due to reduction of soil constituents NO_3^-, CO_2, SO_4, Mn^{4+} and Fe^{3+}
- Reduction of different soil components takes place in a sequential form
- Continuous submergence causes anaerobic conditions except for a thin oxidized layer at the surface
- Nutrients are in reduced forms like NH_4^+, H_2S, Mn^{2++}, Fe^{2++} and CH_4
- Submerged soil is dark gray or bluish gray
- Major products of organic matter decomposition are methane (CH_4), hydrogen sulfide (H_2S), organic acids, alcohols and ketones.

- Several soil redox systems occur in rice soils
- As O_2, is depleted from the soil, NO_3. is utilized by facultative anaerobes and is rapidly reduced
- The reduction of Mn (IV) to Mn (Il) takes place during reduction of O_2, and NO_3,
- Fe(Ill) reduction occurs after O_2, and NO_3,are consumed; carried out by facultative anaerobes
- Reduction of SO_4," to S is carried out by true anaerobic bacteria.
- CH_4, is produced in soils only after most of the sulfate has been reduced

Critical Redox values of oxidized components in submerged soil

Reduction	Redox potential (mV)
$O_2 \rightarrow H_2O$	+380 to +320
$NO_3 \rightarrow N_2$, $Mn^{4+} \rightarrow Mn^{2+}$	+280 to +220
$Fe^{3+} \rightarrow Fe^{2+}$	+180 to +150
$SO_4^{2-} \rightarrow S^{2-}$	-120 to -180
$CO_2 \rightarrow CH_4$	-200 to -280

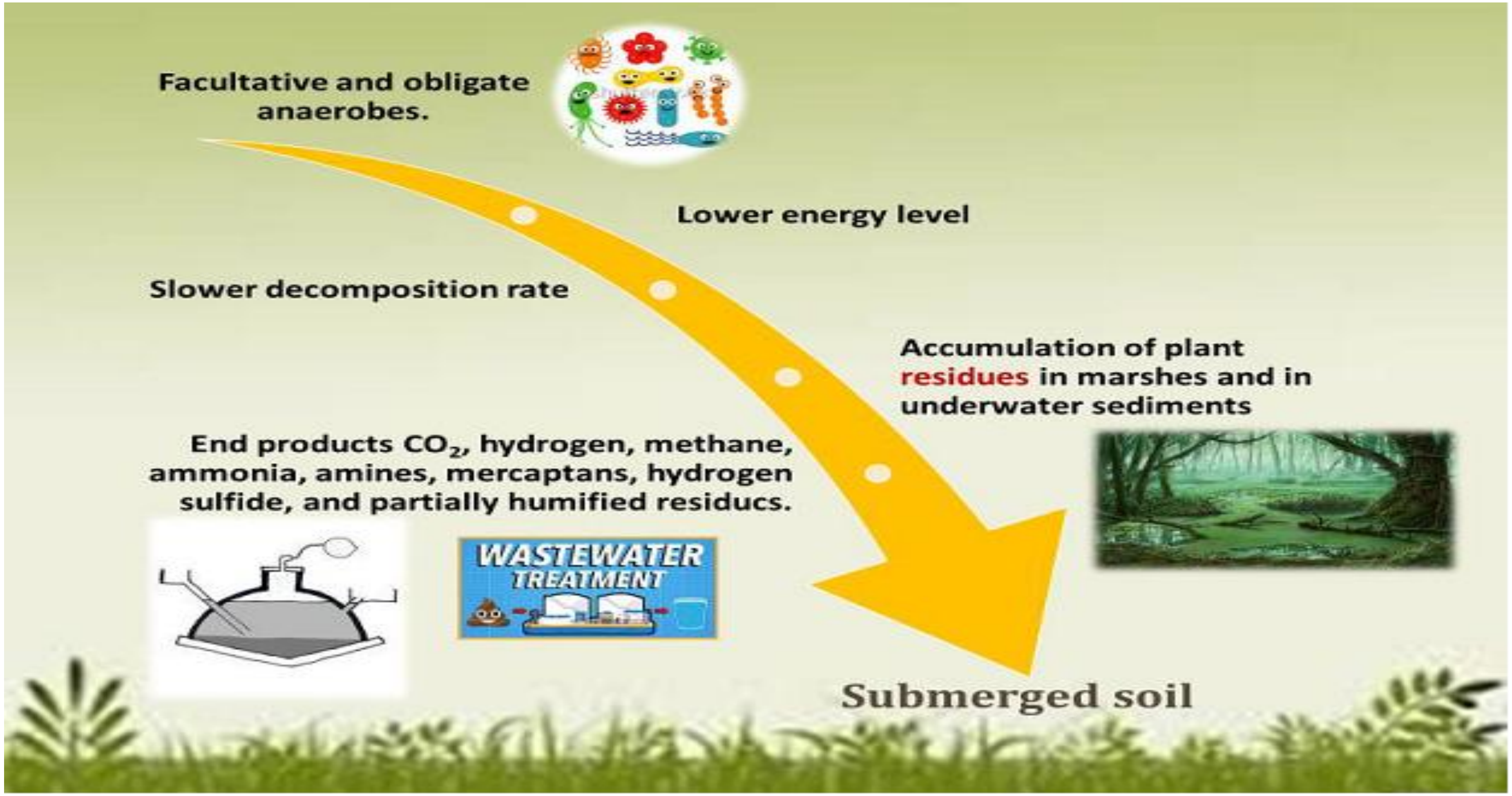


Typical effect of submergence on soil pH for acid, neutral and alkali soil

Chemical Changes and Transformations of Nutrients in Submerged Soil

Element	Aerated soil (Oxidized)	Submerged soil (Reduced)
Oxygen (O)	Oxygen gas (O_2)	Water (H_2O)
Nitrogen (N)	Nitrate ion (NO_3^-)	Nitrogen gas (N_2)
Manganese (Mn)	Manganese IV ion (Mn^{4+})	Manganese II ion (Mn^{2+})
Iron (Fe)	Iron III ion (Fe^{3+})	Iron II ion (Fe^{2+})
Sulfur (S)	Sulfate ion (SO_4^{2-})	Hydrogen sulfide (H_2S)
Carbon (C)	Carbon dioxide (CO_2)	Methane (CH_4)

Transformations of carbon



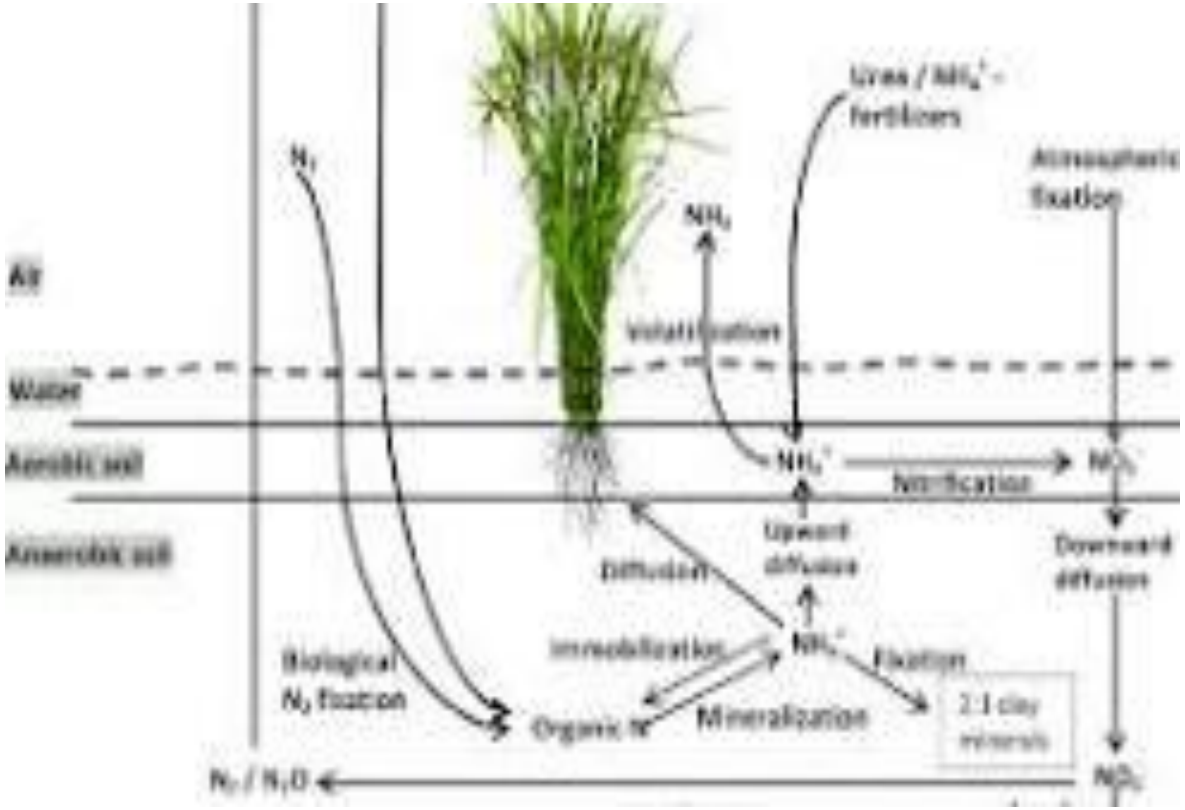
Decomposition of organic matter

- Well drained soil, aerobic microbes will decompose organic matter to form NO_3^-,SO_4^{2-} .
- Submerged condition anaerobic microbes decompose organic matter to produce CO_2, H_2, CH_4, NH_4^+, amines, mercaptans,H_2S and partially humified residues

Transformations of Nitrogen- Pathways

- Ammonification
- Nitrification and denitrification
- Mineralization and Immobilization
- Leaching losses of nitrogen

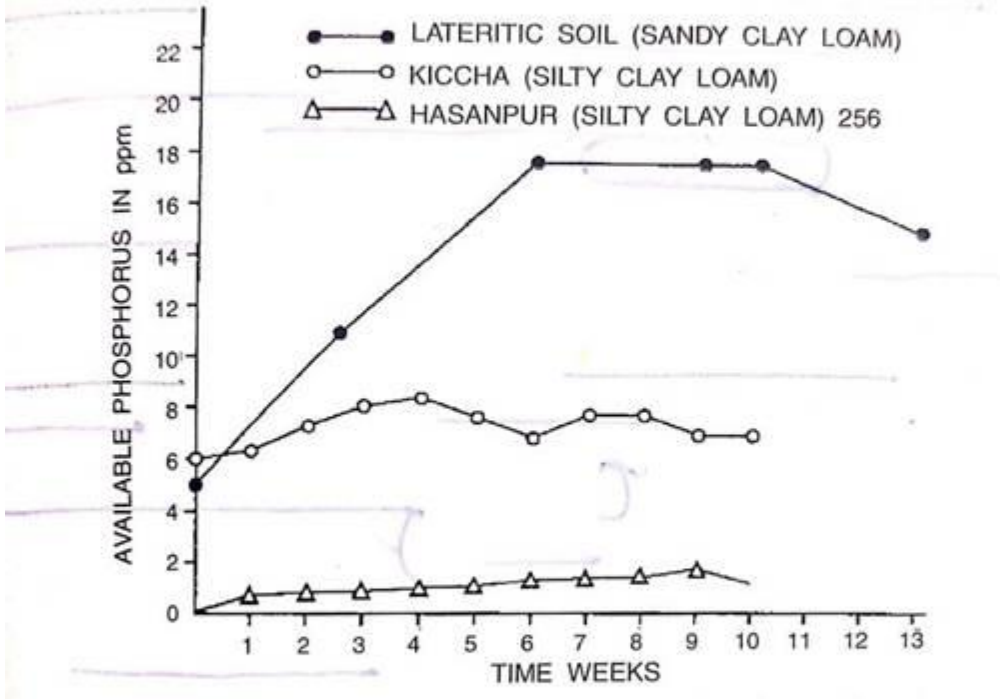
Transformations of Nitrogen



Transformation of Phosphorus

- On submergence, the availability of native as well as applied phosphorus increases
- Phosphorus transformation is also known to be associated with pH changes on submergence.
- Avaailability maximum between pH 6 to 7
- Solubility of iron in the soil usually increase phosphorus solubility.
- Phosphate is chemically associated in an aerobic soil (oxidized soil) as insoluble iron phosphate compounds such as strengite (FePO4.2H2O)
- Soluble phosphate compounds like calcium and magnesium phosphates that are co-precipitated with insoluble ferric oxy-hydroxide
- Aerobic soil on submergence, the concentration of available phosphorus initially increased and thereafter declines with the period of submergence.

Available Phosphorus in submerged soils



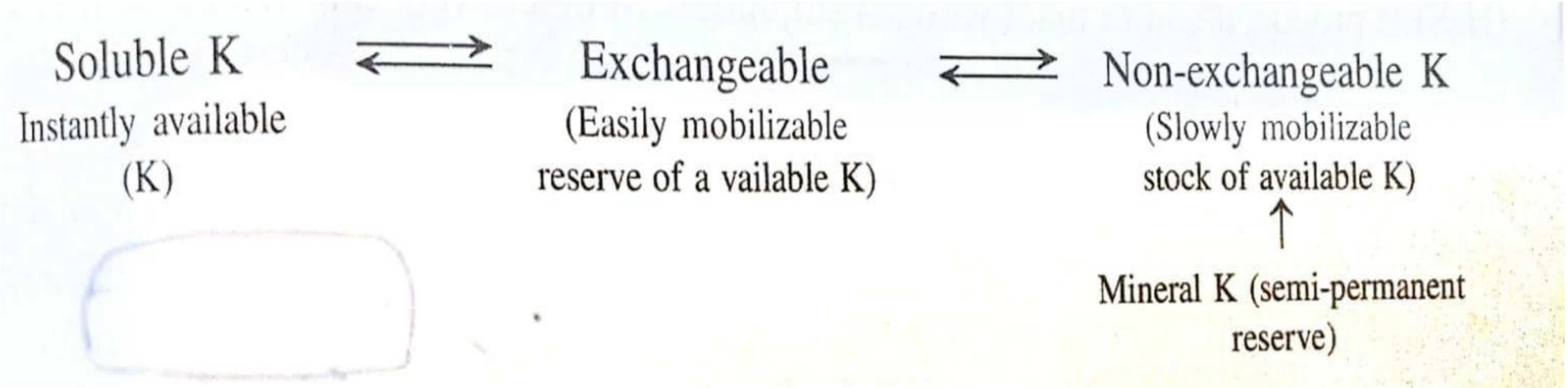
Mechanisms that increase phosphorus availability on submergence

- Release of P from the mineralization of organic residues,
- Reduction of $FePO_4.2H_2O$ to the more soluble $Fe_3(PO_4)_2$, $8H_2O$ and increase in solubility of $FePO_4.2H_2O$ and $AlPO_4.2H_2O$ caused by the increase in pH coupled with the reduction of acid soils.
- Release of co-precipitated or occluded phosphorus due to reduction of ferric oxy hydroxide.(FeO (OH) also called Ferric hydrite
- Displacement of P from ferric and aluminium phosphates by organic anions
- Increased solubility of calcium phosphates ($CaHPO_4.2H_2O$, $Ca_4H(PO_4)_3.3H_2O$, $Ca_{10}(PO_4)_6(OH)_2$, $Ca_{10}(PO_4)_6CO_3$ and $Ca_{10}(PO_4)_6F_2$), associated with the decrease in pH caused by increase in p(CO_2) in calcareous soils.
- Release of P due to anion exchange reactions between clay and phosphate or organic anions and phosphate
- Decrease in the concentration of available P at the later period of submergence may be due to the fixation through adsorption) of released phosphorus by clay colloids (kaolinite, montmorillonite and hydrous oxides of Fe and Al).
- Decreased concentration of phosphorus may also be due to the decreased solubility of phosphorus associated with calcium

Transformations of Potassium

- Two factors influence the availability of K to plants
- Intensity factor (I) which is the concentration of an element in the soil solution
- Capacity factor (Q), which is the ability of solid phases (soil) to replenish element as it is depleted from soil solution.
- As plants remove K+ ions from the soil solution, the concentration of K+ ions in immediate vicinity of roots is reduced and diffusion gradients are established.
- Potassium is present in soils in four forms, which are in dynamic equilibrium

Transformations of Potassium



Potassium availability on submerged soils

- Submergence causes solubility and increase of ferrous (Fe) and manganous (Mn) ions in soil solution which displaces exchangeable K from colloids into the soil solution.
- Release of K from micas may be the contributing factor for the increase in soil solution K
- Rice plants absorbs more K from the non- exchangeable form under submergence than aerated soils

Transformation of Sulphur in submerged soils

- Dominant reduction is of sulphate (SO_4) to H_2S and sulphide (S_2)
- Transformation of the amino acids, cysteine, cystine and methionine to H_2S.
- H_2S react with heavy metals (Zn, Cu, Cd, Pb etc.) to insoluble sulphides reducing availability
- Fe^{3+} reduction to Fe^{2+} precedes SO_4^{2-} reduction,
- Fe in soil solution and hydrogen sulphide (H_2S) forms insoluble iron sulphide (FeS) under submergence
- FeS protects micro-organisms and higher plants from toxicity of hydrogen sulphide (H_2S).
- In muck and sandy soils low in iron, FeS formation retarded and H_2S becomes toxic to rice plant
- In submerged soils availability of sulphur decreased due to reduction of sulfates to S
- In rice plants oxidation of S to sulfate on the root surface enables absorption

Iron under submergence

- Dominant chemical reaction is reduction of Ferric iron to soluble Ferrous
- .Intensity of reduction, depends on time of submergence, amount of OM, active
- iron, active Mn, nitrate etc.
- On reduction, colour of soil changes from brown to grey and large amounts of Fe2- enter the soil solution.
- (Fe2+) concentration increases initially to peak value and further decreases slowly with the period of soil submergence.
- Organic matter also enhances the rate of reduction of iron in submerged soils.

$$\underset{\text{(Insolule)}}{Fe(OH)_3} + e^- \xrightleftharpoons{\text{Reduction}} \underset{\text{(Soluble)}}{Fe^{2+}} + 3OH^-$$

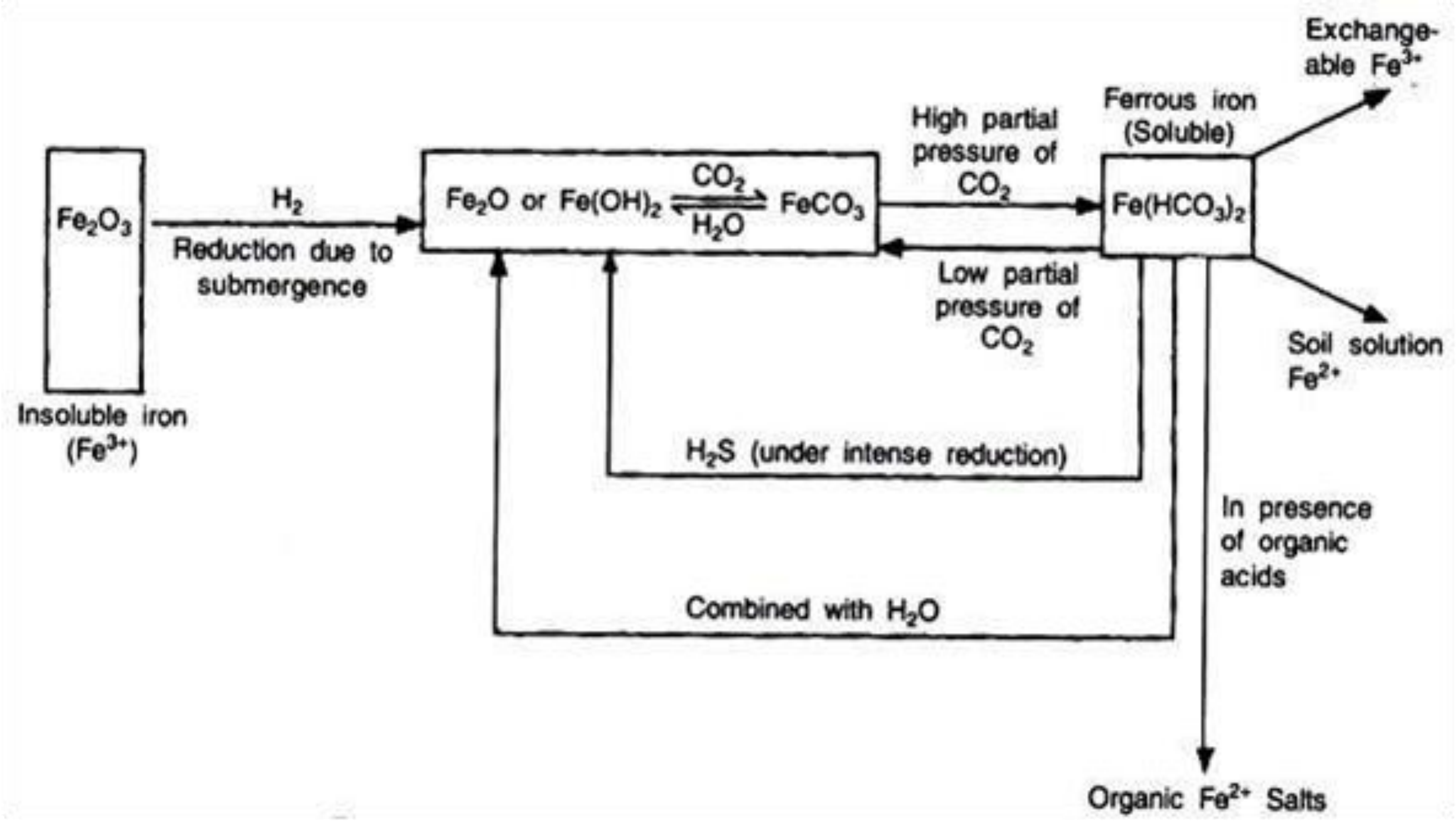
- In calcareous soils rease in the concentration of Fe^{2+} following the peak rise is by the precipitation of Fe^{2+} as FeC03 in the early stages due to high partial pressure of CO_2
- $Fe_3(OH)_8$ precipitation occurs due to decrease in the partial pressure of CO_2(P_{CO_2})

$$\underset{\text{(Soluble)}}{2Fe^{2+}} + 3CO_2^{+} \longrightarrow \underset{\text{(Insoluble)}}{2FeCO_3}$$

Consequences of Iron Reduction

- Water soluble iron increases, with increase in pH increases,
- Cations are displaced from exchange sites
- Solubility of P and Si increases and new minerals are formed.

Transformations of iron in submerged soil

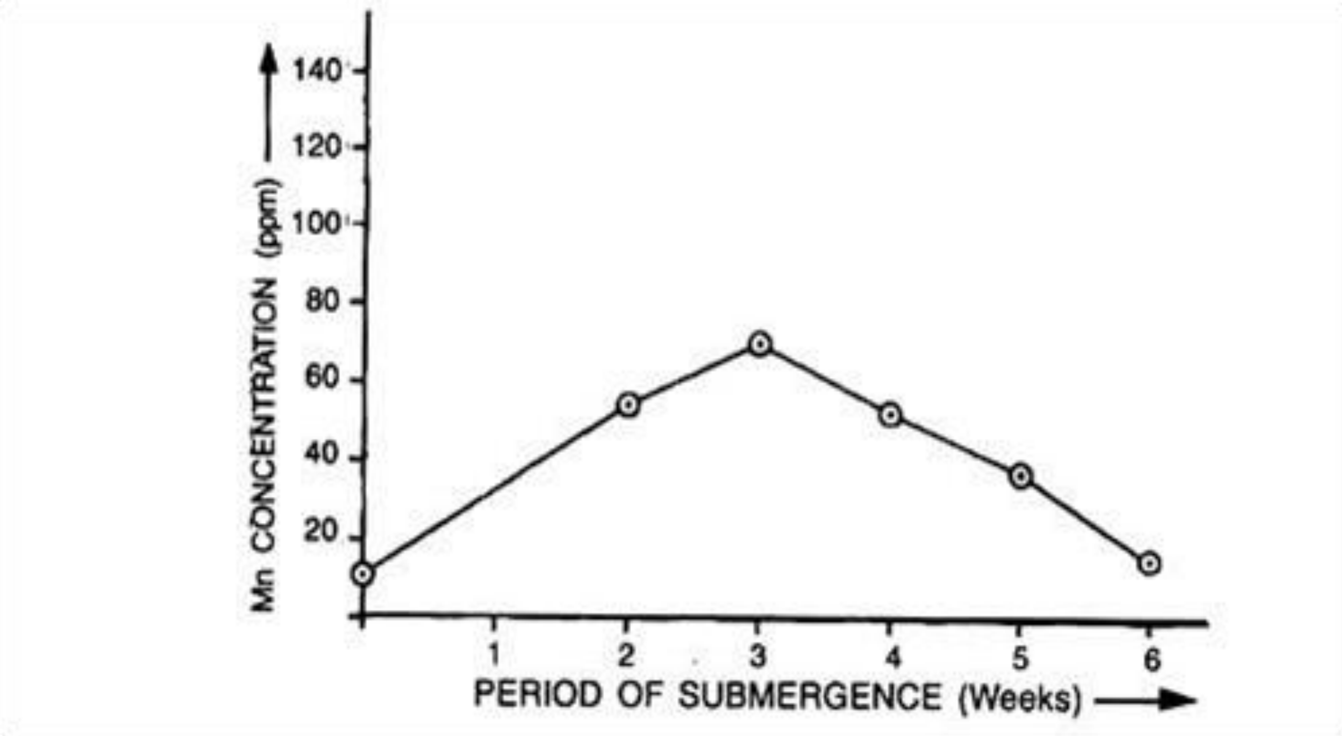


Manganese in Submerged soil

- Transformation of Mn4+ to Mn2+
- In submerged soil transformation of Mn results in increase in concertation of
- water soluble Mn2+ and later precipitation of Manganous carbonate (MnCO3).
- When the aerobic laterite soils are submerged, the reduction of Mn4+ occurs concurrently with nitrate reduction, but precedes Fe reduction.
- Water soluble (Mn2+) increases initially and decline with period of submergence.
- Reduction of Mn4+ occurs when redox potential is within range from +200 to +400 mV.

$$MnO_2 + 4H^+ + 2e^- \xrightleftharpoons{\text{reduction}} \underset{\text{(Water soluble)}}{Mn^{2+}} + 2H_2O$$

Transformations of Manganese



$$Mn^{4+} \xrightarrow[\text{submerged condition}]{\text{reduction}} Mn^{2+}$$

(occurs at a redox potential value of +200 to +400 mV)

Zinc on submergence

- Zinc deficiency in submerged rice soils is very common owing to the
- Combined effect of increased pH, HCO_3^- and sulfide formation.
- Solubility of native forms of Zn in soils is highly pH dependent and decreases by a factor of 10^2 for each unit increase in soil pH

Decreased availability of Zn in Submerged soils due to

- Formation of insoluble franklinite ($ZnFe_2O_4$) compound on submergence.

$$Zn^{2+} + 2Fe^{2+} + 4H_2O \; ZnFe_2O_4 \text{ (franklinite)}$$

- Formation of very insoluble compounds of Zn as ZnS under intense reducing conditions,

$$Zn^{2+} + S^{2-} \; ZnS \text{ (Sphalerite)}$$

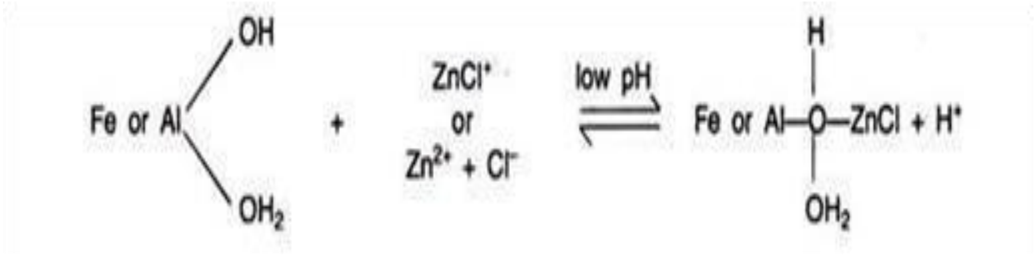
- Formation of insoluble forms of Zn as $ZnCO_3$ at the later period of soil submergence owing to high partial pressure of CO_2(pCO_2) arising from the decomposition of organic matter

$$Zn^{2+} + CO_2 \; ZnCO_3 \text{ (Smithsonite)}$$

- Formation of $Zn(OH)_2$ at a relatively higher pH
- Adsorption of soluble Zn^{2+} by oxide minerals e.g. sesquioxides, carbonates, soil organic matter and clay minerals etc.

Mechanisms of Zinc Adsorption

1 $$Zn^{2+} + 2HO^- \rightleftharpoons \underset{\text{(Insoluble)}}{Zn(OH)_2}$$

2 

Boron and Molybdenum in submerged soils

- Availability very much dependent on pH, organic matter, clay content
- Submerging an acid soil caused an increase in the amount of available Mo during the initial period, which remained constant at the later period.
- Increase in soil pH desorption of MoO_4 from oxides and hydroxides of Fe and Mn.
- Concentration of B in soil solution remains more or less constant after submergence

Reference

Ponnamperuma, F.N. (1972). The Chemistry of Submerged Soils, Reprinted from: Advances in Agronomy, Vol. 24, ©1972,Academic Press, Inc


Thank You