Chemical Properties and Nitrogen Transformations in Submerged Soils

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Rice is the staple food crop of the nation spreading over an area of 45 m.ha with a total production of 130 m.tonnes. But rice ecosystem is fragile and grows in wide range of moisture regimes starting with submerged lowland to water deficit upland system. Thus, several physical, physico chemical and biochemical changes occur under submergence and are important in determining the suitability of soil for rice production.

Depletion of oxygen

The immediate effect of submergence is creation of anaerobic condition due to replacement of air in the capillary pores. Within few hours after submergence, most soil layers turn virtually oxygen free. Soil microorganisms utilize oxidized soil constituents and organic metabolites instead of molecular oxygen for the respiration process causing reduction in soil. Anaerobic condition influences the availability of several plant nutrients and the production of toxic substances in the soil. Rice is able to manage submergence as its roots receive oxygen through aerenchyma in the shoot system and lysigenous chemicals in the roots. Under anaerobic conditions, facultative and true anaerobic organisms become active. Organic matter decomposition is slower and less complete in anaerobic than in aerobic soils.

Decrease in redox potential

Whenever an aerobic soil is submerged, it undergoes reduction and its redox potential (Eh) drops to a fairly stable value of +0.2 to -0.3 V depending on the soil, but the redox potential in the surface water and the first few millimeters of top soil remains at +0.3 to + 0.5 V (Ponnamperuma, 1972). Major portion of the root zone of submerged soil is reduced but the subsoil and spots in the reduced matrix as well as streaks may be oxidized. The reduction in Eh has twin benefits on rice growth. The benefits include increase in supply of nitrogen, phosphorus, potassium, iron, manganese, molybdenum and silicon. The disadvantages include loss of nitrogen by denitrification, decrease in availability of sulphur, copper and zinc.

Changes in pH

The prime effect of submergence is increase in pH of acid soils and decrease in pH of sodic and calcareous soils. Within a few weeks of submergence, pH of acid and alkaline soils converges to neutrality. The change in pH can be attributed to conversion of ferric to ferrous iron, accumulation of ammonium, change of sulphate to sulphide and change of CO_2 to methane under reducing conditions. However, this strategy is not true for acid sulphate soils as they may not attain a pH of 6.0 even several months after submergence (De Datta, 1933).

Changes in Electrical Conductivity

Electrical conductivity of the soil solution in most of the soils increases after submergence. Organic matter decomposition producers' bicarbonate and organic ions and serve as energy source for the reduction of insoluble inorganic compounds to soluble ionic forms. Fe (III) oxide hydrates are reduced to Fe (II) compounds and consequently the colour changes from brown to gray and large amounts of Fe (II) enter into solution phase. The concentration of water-soluble iron may vary from 0.1 ppm shortly after submergence and shoot upto as high as 600 ppm. In acid sulphate soils, the concentration may be as high as 5000 ppm within few weeks after submergence (Ponnamperuma, 1976). In flooded soils, reduction of higher oxides of manganese (Mn (IV)) takes place with denitrification. Manganese is more readily reduced and rendered soluble than iron. Availability of nitrogen in flooded soils is higher than in non-flooded soils. Availability of phosphorus, silicon and molybdenum in soil increases after flooding. However a decrease in concentration of water soluble zinc and copper is the major disadvantage of flooding. Increased availability of phosphorus could be attributed to the reduction of ferric phosphate to ferrous phosphate, hydrolysis of aluminium phosphate and the dissolution of calcium phosphate resulting from the accumulation of carbon di oxide.

Production of Toxins

Due to sulphate reduction and anaerobic decomposition of organic matter, accumulation of hydrogen sulphide occurs in flooded soils. In normal soils, hydrogen sulphide is rendered harmless due to precipitation as ferrous sulphide but in soils high in sulphate and organic matter and low in iron, it may harm rice plants. Organic acids like acetic acid, butyric acid, formic acid, propionic acid and lactic acids are formed and the organic reduction products produced in anaerobic soils harm rice plants.

Nitrogen Transformations

Nitrogen is the King pin of nutrients and the most crucial element in flooded ecosystem. About 95 % of the nitrogen in soil is present in organic form and the inorganic nitrogen constitutes only a portion of the total nitrogen. Most of the inorganic nitrogen present in the reduced soils is water soluble or adsorbed on the exchange complex. In flooded rice soils, accumulation of ammonia is common as mineralization of organic nitrogen does not proceed beyond the ammonium stage in the absence of oxygen as oxygen is required for microbial conversion of ammonium to nitrate. Nitrite form of nitrogen may accumulate which is mainly attributed to the oxidation of ammonium to nitrite by microorganisms *Nitrosomonas* and *Nitrococcus.* Nitrite is an intermediate product of nitrification process. In submerged ecosystem, nitrate rapidly disappears through denitrification, leaching and plant uptake. Ammonium is fixed in the lattice structures of silicate minerals which is neither water soluble nor readily exchanged.

Nitrous oxide and elemental nitrogen are formed in flooded soils.

Mineralization of nitrogen include hydrolysis of proteins into polypeptides and aminoacids with subsequent deamination in the form of ammonia. Majority of the nitrogen containing compounds that are present in the submerged ecosystem is finally converted to ammonia. Apart from plant uptake nitrogen losses in the soil occur mainly from denitrification, ammonia volatilization, leaching and surface run off. Immobilization and ammonium fixation make nitrogen temporarily unavailable to the rice crop but donot cause loss of nitrogen from the soil system.

Severe nitrogen losses occur in soils subjected to alternate wetting and drying. Soil microorganisms mediating denitrification functions best near pH 7. Ammonia volatilization loss occurs from flood water on a soil moderately to slightly acidic, although losses are usually high on alkaline soils. When pH of the soil solution rises above 7.4, ammonia volatilization losses may be appreciable.

Soil pH may influence ammonia volatilization and at higher soil pH, the losses are high. Up to a pH 9.0, ammonia concentration increases by a factor of 10 per cent for unit increase in pH. The high temperatures and solar radiation that prevail in the dry season increases ammonia losses through volatilization. Leaching of nitrate and ammonium nitrogen also contributes substantially to the loss of nitrogen. Nitrate produced in the oxidized surface layer of a flooded soil moves easily by diffusion and percolation to the underlying reduced layer, where it is rapidly denitrified. Leaching loss of nitrate is higher compared to ammonium fixation especially in coarse textured soil.

Urea nitrogen is taken up by the rice crop after urea is hydrolysed to $(NH_4)_2CO_3$. The hydrolysis site is soil rather than flood water. Unlike ammonium urea is only weakly adsorbed by soil colloids. Hence losses by leaching and run off is high if hydrolysis of urea is slow. Urease activity is the highest in alkaline conditions than in acidic conditions.

Biological nitrogen fixation is the most prominent phenomena in submerged ecosystem. The principal agents of biological nitrogen fixation are the water fern, azolla in association with blue-green algae, non-symbiotic nitrogen fixation around the plant's root zone and in anaerobic soil. Thus, the flooded rice ecosystem is a fragile system with numerous nutrient transformations and meticulous nutrient management is warranted to achieve the full potential of the system.

References

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