MICROBIAL TRANFORMATIONS IN FLOODED SOILS

Flooding is beneficial particularly for rice cultivation by:

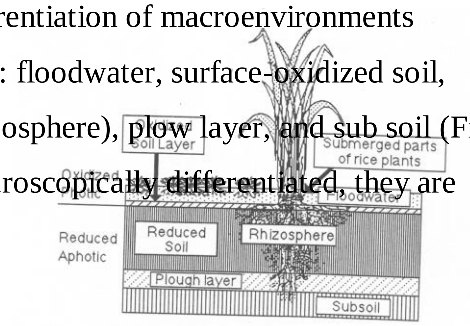
- bringing the soil pH near to neutrality,
- increasing availability of nutrients, especially P and Fe,
- stimulating biological nitrogen fixation,
- depressing soil-borne diseases,
- supplying nutrients from irrigation water,
- decreasing weed incidence, and
- preventing water percolation and soil erosion

Flooding changes the chemistry, microbiological properties, and nutrient supply capacity of soil. It leads to the differentiation of macro- and microenvironments differing in redox state, physical properties, and light and nutrient status that allows a wide range of microorganisms to be active. In particular, all kinds of N_2 fixing microorganisms (aerobes, facultative and strict anaerobes, heterotrophs, phototrophs, free-living, and symbiotic) can and do grow in wetland rice fields, resulting in a unique agroecosystem in which moderate, but constant, yields have been obtained after continuous cropping for centuries without N fertilizer addition.

MAJOR ENVIRONMENTS AND MICROBIAL ACTIVITIES

Diffusion of air into soil is reduced about 10,000 times when a rice field is flooded and O_2 supply cannot meet the demand of soil aerobic organisms. Facultative and strict anaerobes proliferate, using oxidized soil substrates for respiration and creating anaerobic conditions in a reduced layer a few milimeters beneath the soil surface.

Flooding and crop growth lead to the differentiation of macroenvironments differing in physiochemical and trophic properties: floodwater, surface-oxidized soil, reduced soil, rice plants (submerged parts and rhizosphere), plow layer, and sub soil (Fig. 1). Although these microenvironments can be macroscopically differentiated, they are



more or less continuous. In particular, continuous exchanges take place between flood water and oxidized soil. Macroenvironments might also be heterogenous in their oxidation-reduction status at microsite level because the activity of soil fauna creates microaerophilic sites in the reduced layer, while organic matter debris and aggregates might provide anaerobic microsites in the oxidized soil layer and the water.

Floodwater:

The floodwater is a photic, aerobic environment in which chemotrophic and photosynthetic producers (bacteria, algae and aquatic weeds), primary consumers (grazers), and secondary consumers (carnivorous insects and fish) recycle nutrients and provide organic matter to the soil. The floodwater is subject to large variations in insolation, temperature, pH, O_2 concentration, and nutrient status. Because of the photosynthetic activity of algae and aquatic plants, O_2 content and pH exhibit marked diurnal variations. During daytime, pH may increase above 10 and O_2 may be oversaturated by 200%.

The photosynthetc aquatic biomass that develops in flood water is composed of planktonic, filamentous, and macrophytic algae and vascular macrophytes. Populations of heterotrophic bacteria in the flood water may attain 10^5-10^6/mL depending upon the quantity of soil particles in suspension in water. Major activities in the floodwater include photosynthesis and respiration by the photosynthetic aquatic biomass, and photodependent biological N_2 fixation by free-living and symbiotic blue green algae.

Oxidized soil layer:

The oxidized soil layer is a photic aerobic environment, with a positive redox potential, in which NO_3^{-2}, Fe^{+3}, SO_4^{-2}, and CO_2 are stable, and algae and aerobic bacteria predominate. The depth of the oxidized layer, which is usually between 2 and 20 mm, depends on the quantity of O_2 dissolved in floodwater, the reducing capacity of the soil

(C content), the water percolation, and the activity of the soil and water fauna. After land preparation, algae develop at the soil surface and support grazing populations. Later in the crop cycle, organic matter accumulates at the soil surface and supports populations of the invertebrates that recycle the nutrients.

The oxidized soil layer is microbiologically very active. Major activities include 1) aerobic decomposition of organic matter, 2) photodependent biological N_2 fixation by algae and photosynthetic bacteria, 3) nitrification by ammonium and nitrite oxidizers, and 4) methane oxidation.

Reduced soil layer:

The reduced soil layer is a nonphotic, anaerobic environment for which the soil Eh is predominantly negative, and the Eh of the soil solution is lower than 300 mV. The reduction processes predominate; Eh and pH are low enough to allow the reduction of iron oxide. NH^{+4}, S^{-2}, Mn^{+2}, and Fe^{+2} are stable chemical forms, and microbial activity is concentrated in soil aggregates containing organic debris. The equilibrium of oxidation and reduction depends strongly on microbial growth and behaviour and on the degree to which reacting products diffuse and mix.

Major activities in the reduced soil layer include 1) anaerobic decomposition of organic matter, 2) heterotrophic biological N_2 fixation mostly associated with organic debris, 3) denitrification, 4) manganese reduction, 5) iron reduction, 6) sulfate reduction, 7) methanogenesis, and 8) H_2 production.

Rice Plant: submerged parts and rhizosphere:

From a microbiological point of view, the rice plant provides two environments for the microflora: submerged plant parts and the rhizosphere.

Submerged portions of rice shoots (and aquatic plants) are colonized by epiphytic bacteria and algae. Epiphytic biological N_2 fixation can be agronomically significant in deep-water rice.

The rhizosphere is a nonphotic environment in which redox conditions are determined by the balance of the oxidizing and reducing capacities of rice roots, and production of C compounds by roots provides energy source for microbial growth. The rice plants' ability to transport O_2 from the stem to the root and diffusion of this O_2 in the adjacent soil layer lead to the differentiation of oxidized-reduced interface. Because rice roots can occupy a large volume, a significant fraction of the planted soil can be aerobic, and the soil solution can maintain a high redox potential.

Major activities in the rhizosphere include 1) associative heterotrophic biological N_2 fixation, 2) nitrification-denitrification, and 3) sulfate reduction.

Plow pan and subsoil:

The plow pan exhibits low permeability and a higher bulk density and mechanical strength than other soil layers. It acts to reduce water and nutrient losses by leaching and percolation. The soil below the plow pan is aerobic in well-drained soils and anaerobic in poorly drained soils. It is microbiologically active in its upper layer, and its role in providing nutrients to rice, especially N, should not be underestimated.