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Chapter 4. Physical Changes in Flooded Soils and the Growth of Rice

The main feature that differentiates wetland rice culture from dryland crop culture is the presence of a layer of standing water in the field during the greater part of the growing season.

Standing water helps weed control and eliminates water stress. The depth has no effect on yield provided it is less than 10 cm (Wickham and Sen 1978). Evaporation of standing water leads to the deposition of insoluble carbonates, water-soluble salts, and silica. That may lead to a build-up of salt, alkalinity, and high boron concentrations, causing land degradation (Ponnamperuma 1979). On the other hand irrigation water can be a substantial source of potassium and sulfur. Assuming that 1 m of water is used per crop, 1 ppm of an element corresponds to 10 kg/ha per crop.

Apart from these effects, flooding a soil:

1. drastically retards gas exchange between soil and air
2. stabilizes soil temperature
3. causes swelling of colloids
4. destroys aggregates
5. reduces permeability

1. Retardation of gas exchange

Oxygen deficiency - The moment a soil is flooded, its oxygen supply is virtually cut off. Oxygen can enter the soil only by molecular diffusion in the interstitial water. The process is 10,000 times slower than in gas-filled pores. Thus the oxygen diffusion rate suddenly decreases when a soil reaches saturation by water. Within a few hours of flooding, microorganisms use up the oxygen present in the water or trapped in the soil and render a submerged soil practically devoid of molecular oxygen.

A flooded soil, however, is not uniformly devoid of oxygen: the oxygen concentration may be high in the surface layer which is a few millimeters thick and in contact with oxygenated water. The thickness of the layer represents a balance between diffusion from the flood water and oxygen consumption by the soil. It increases in thickness as the crop matures. Below the surface layer, the oxygen concentration drops abruptly to practically zero. The brown color of the oxygenated layer, its chemical properties, and its oxidation-reduction potential undergo a similar abrupt change with depth in submerged soils. The root zone of rice is practically free of molecular oxygen (Ponnamperuma 1972).

If the root zone of rice is devoid of oxygen, how do rice seeds germinate and grow, and rice roots grow and accumulate nutrients without oxygen? Rice can germinate at oxygen pressures of less than 3 millibars because of a highly developed system of anaerobic respiration. But growth is retarded (Kordan 1974) and seedling establishment adversely affected at low oxygen.

Rice roots, like the roots of dryland plants, need oxygen for growth and nutrient accumulation. The source of oxygen is oxygen gas diffusing from the aerial parts through aerenchyma continuous with the roots (van Raalte 1941, Armstrong 1970).

<u>Accumulation of carbon dioxide –</u> The presence of a layer of water also drastically cuts down the escape of soil gases. Carbon dioxide, methane, hydrogen, and nitrogen produced in the soil tend to accumulate, build up pressure, and escape as bubbles. The partial pressure of carbon dioxide in a soil increases after submergence and reaches a peak of 0.2 – 0.8 bars 1-3 weeks later. Carbon dioxide injury to rice may occur on acid soils low in iron, in organic soils, and cold soils.

2. Stabilization of soil temperature

The effects of flooding on soil temperature follow from three important thermal properties of water – its high specific heat, high latent heat of vaporization, and a higher thermal conductivity than soil material. The high specific heat prevents violent temperature fluctuation. The high heat of vaporization tends to keep flooded soils cooler than dry soils. The cooling effect is used to reduce high temperature injury in hot locations while the stabilizing effect is used to prevent low temperature injury at night.

Standing water markedly influences the microclimate of the first 50 cm above the soil surface (Nagai 1958). Introduction of cold or warm water into the field rapidly changes the temperature of soil, air, and plants.

Low soil temperatures retard mineralization of organic nitrogen and phosphorus and favor the accumulation of carbon dioxide, organic acids, and excess water-soluble iron in flooded soils (Cho and Ponnamperuma 1971, Ponnamperuma 1976). The adverse effects of low soil and water temperatures are present in tropical soils above 1000 m and in soils irrigated by cold, mountain streams.

Low water temperature reduces germination, retards growth, and depresses grain yield. Grain yield is reduced if the water temperature is less than 17 degrees C during the active tillering and meiotic stages. Rice with panicle primordia above the water level suffered less yield reduction (IRRI 1980).

3. Swelling of colloids

When a dry soil is flooded, soil colloids absorb water and swell. The rate of water sorption and volume increase of mineral soils depend on the clay content, type of clay mineral, and the nature of the adsorbed cations. Swelling is usually complete in one to three days. The higher the clay content the greater the swelling. The expanding-lattice type of clays (montmorillonite and beidellite) swell more than the fixed-lattice type (kaolinite and halloysite). Sodium clays swell more than calcium and potassium clays. When a puddled soil is dried, it shrinks and the decrease in volume equals the volume of water lost. Deep cracks are common in puddled rice fields after draining and drying. They cause heavy loss of water by percolation during reflooding (Wickham and Singh 1978).

<u>Consistency</u>

As the moisture content of a soil increases the cohesion of water films around soil particles causes them to stick together rendering the soil plastic. At this moisture content soils are easily puddled. At higher moisture contents (as in flooded soils), cohesion decreases rapidly, making tillage easy. But penetration increases and soil strength decreases, rendering the use of heavy machinery impractical on flooded soils.

4. Destruction of soil aggregates

When a dry soil is flooded, the aggregates become saturated with water. During the process, internal air pressure disrupts the aggregates (Baver et al 1972). Swelling of colloids and dissolution of cementing agents, such as iron oxide, further decrease aggregate stability. Sodic soils show marked aggregate breakdown on flooding, whereas soils high in iron and aluminum oxides and organic matter suffer little aggregate destruction (Sanchez 1976). On soil drying and oxidation, reaggregation occurs through soil cracking and cementing by higher oxides of iron.

5. Reduction of permeability (percolation rate)

Flooding decreases percolation rate in soils of low permeability even without puddling. This has been attributed to dispersion of soil particles, swelling, aggregate destruction, and clogging of pores by microbial slime. In porous, nonswelling soils, flooding (by providing a greater head of water) increases percolation (Wickham and Singh 1978).

SUMMARY

A characteristic feature of wetland rice culture is the presence of a layer of standing water in the field.

Standing water retards gas exchange between soil and air, stabilizes soil temperature, causes swelling and destruction of soil aggregates and reduces permeability.

Standing water favors rice by eliminating water stress, controlling weeds, reducing the soil, and increasing the availability of nutrients. Rice can grow in reduced soils because it has an oxygen transport system from shoot to roots.

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