

GROWTH OF RICE IN RELATION TO THE SOIL-WATER REGIME

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Two broad categories of rice fields can be recognized on the basis of the soil-water regime, and on their location in the soil catena, viz. lowland and upland fields.

Lowland fields are sited on alluvial soils or on low-humic gleys occupying the lowest level in the soil catena. The poor drainage of gley soils prevents the successful growing of any crop but rice. Lowland fields are submerged for much of the crop duration.

In Sri Lanka's Dry Zone, upland fields are located mainly on reddish brown earths or non-calcic brown soils, and occupy the highest levels in the soil catena. Upland rice usually depends completely on incident rainfall. Water stress often afflicts upland rice and may be eased by supplementary irrigation.

LOWLAND RICE

Rice owes its unique tolerance of an anaerobic soil environment to exceptional physiological and structural characteristics which are outlined below.

Seed Germination

As early as 1905, Japanese physiologists showed that the rice caryopsis could germinate in oxygen-free water. Subsequent work in the USA identified this ability with the existence in the rice caryopsis of a mechanism for anaerobic respiration (Erygin 1936 & Taylor 1942).

In California, rice is seeded by plane into eight inches of standing water. A comparable practice obtains in Hokkaido. Seeding into standing water becomes less popular as one proceeds to the warmer south, both in the USA and Japan, presumably on account of the higher incidence of fungus invasion of germinating seed.

Seedling Growth

Rice seedlings manifest marked growth under submersion. Low oxygen tensions promote plumule development, but depress radicle growth. Improved aeration accelerates radicle elongation but retards plumule growth (Vlamiš & Davis 1943).

Adult Growth

Rice is unique among crop plants in its possession of a mechanism for shoot-to-root transport of oxygen. The mechanism, which consists mainly of extensive intercellular spaces in the parenchyma of the root cortex, permits

the downward diffusion of oxygen, and makes the aerobic functioning of rice roots in a relatively anaerobic medium possible (Van Raalte 1941). The quantity of oxygen supplied to rice roots in this way approximates 0.8 mg per hr per sq cm of root cross section. Nearly 20 per cent of this oxygen is derived from leaf photosynthesis; atmospheric oxygen provides the balance (Yamada *et al*).

An additional mechanism becomes operative in adult rice. At the termination of the tillering phase, apart from the coarse roots which ramify sparsely in the soil mass, a surface system of fine, profusely branched, diageotropic roots assumes respiratory functions, and supplements the leaf-to-root oxygen transport which may be increasingly obstructed by stem elongation (Alberda 1953).

Benefits of Soil Submersion

Soil submersion, apart from its contribution to weed control and to the elimination of water stress, induces a series of chemical reactions, several of which are advantageous to a crop that can survive under the conditions of oxygen depletion implicit in inundation.

Submersion depresses the pH of alkaline soils and raises that of acid soils; the final value approximates neutrality.

Nutrient benefits that derive from soil submersion are mainly the consequence of a drop in redox potential, and include the following:

(a) *Reduction of ferric and manganic compounds to the more soluble ferrous and manganous forms.*

The increased solution of iron and manganese that follows reduction benefits rice as its requirements in iron (Gile & Carrero 1916 & 1920; Gericke 1930; Lin 1946) and manganese (Aiyar 1946) greatly exceed those of most other plants.

(b) *Increase in phosphate availability associated with the reduction of ferric phosphate to ferrous.*

Ferrous phosphate is much more soluble particularly outside the pH range 4.5 to 7.0 (Aoki 1941).

(c) *Increase in the soil content in dissolved silica,*

During the whole of its life, the rice plant absorbs large quantities of silica from a submerged soil. The silica content of the aerial parts of a rice plant averages 12-14 per cent. On degraded soils, however, the silica content may be as low as 5-9 per cent.

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The deposition of silica is mainly in the leaf and stem epidermis, and contributes to the resistance of this tissue to invasion by the blast fungus, *Piricularia oryzae*. Silicification of the epidermis obstructs the exudation of solutes that stimulate the germination of fungus conidia.

Silica entering rice roots moves in the transpiration stream. Factors that retard the transpiration rate depress tissue silicification and consequently blast resistance; hence the susceptibility of transplants from upland nurseries to blast.

Deleterious Effects of Soil Submersion

Both the favourable and undesirable effects of soil submersion are mainly the result of a fall in redox potentials.

(a) The earliest effect of soil submersion is the elimination of nitrates by reduction to nitrites, and ultimately to nitrogen gas.

(b) Hydrogen sulphide which develops in quantity at low redox potentials, consequent on the reduction of sulphates and of organic matter, exercises its toxic effects mainly through its action as a respiration inhibitor. Hydrogen sulphide depresses nutrient uptake, particularly the uptake of potassium. Protein synthesis is obstructed directly by the depressant effects on respiration, and indirectly through the lower availability of potassium, an element that promotes this synthesis.

Ferrous iron in submerged soils precipitates hydrogen sulphide as insoluble FeS. In soils deficient in reduced iron, e.g. degraded soils, hydrogen sulphide toxicity presents problems. Hydrogen sulphide damage in such soils can be alleviated by (i) the exclusion of sulphur-containing fertilizers, e.g. sulphate of ammonia and ordinary superphosphate, (ii) preventing too great a drop in redox potentials and too high a rise in pH values, and (iii) addition of iron-rich upland soil.

(c) The anaerobic decomposition of organic matter in submerged soils leads to the accumulation of carbon dioxide, organic acids (e.g. butyric acid), methane and hydrogen sulphide. Carbon dioxide has at least one favourable effect: it depresses the pH of alkaline soils, and ensures that submerged soils have a reaction approximating to neutrality.

UPLAND RICE

Over 15 per cent of the world's rice area is sown in upland rice. The crop is particularly popular in Africa and Latin America; upland rice occupies nearly 75 percent of the total rice acreage in each of these two regions. Grain yields are, however, pathetically poor: upland rice yields average 0.5 t/ha in Africa, and under 1.5 t/ha in Latin America.

In Sri Lanka, even when irrigation supplements rainfall, upland rice yields average less than half those of inundated lowland rice in the same catena. The arguments for the complete exclusion of upland rice from this country's future cropping programs are set out below.

As has been explained at length earlier, the rice plant possesses structural characteristics which adapt it admirably for growing in anaerobic soils. These structural peculiarities, though advantageous in submerged soils, seriously handicap the growth of rice on upland soils.

Dry-foot crops have reducing rhizospheres which ensure the availability of soluble ferrous iron. The special mechanism that the rice plant possesses for shoot-to-root transport of oxygen creates an oxidising rhizosphere in which iron remains in insoluble ferric form and thereby obstructs iron uptake by upland rice. Moreover, in aerobic soils, silica uptake is depressed, and at low pH values, manganese and aluminium toxicities occur (Ponnamperuma 1982).

When upland rice receives supplementary irrigation, economic considerations obtrude. In irrigated agriculture, water becomes the scarce resource, not land; the choice of crops is determined by the economic benefit per unit of water issued.

NEDECO* estimates the return per unit of irrigation water for upland rice and dry-foot crops in the Mahaweli area as follows:

	<i>Net Crop benefits per ha</i>	<i>Water consumed</i>	<i>Return per cu. m water</i>
Upland rice	c. Rs. 8,000	c. 23,000 cu-m	Rs. 0.35
Dry-foot crops (soybeans, groundnuts, pulses).	c. Rs. 4,500	c. 6,000	Rs. 0.75

On the basis of the return per unit of irrigation water, dry-foot crops are the obvious choice.

ACRES** arrived at similar conclusions for the Mahaweli area: upland rice consumes (a) 1.6 times as much irrigation water as lowland rice, and (b) three times as much irrigation water as dry-foot crops.

ACRES estimated the annual returns per unit of water—defining a unit of water as the quantity that irrigates one hectare of dry-foot crops—as follows:

Lowland rice	Rs. 7,782
Upland rice	Rs. 3,891
Dry-foot crops	Rs. 6,785

* "Mahaweli Ganga Development Programme Implementation Strategy Study. Annex F Land Resources & Agricultural Benefits", 1979.

** "Maduru Oya Project Feasibility Report—m Study of Upland Farm Size", 1980.

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It is abundantly clear that under conditions of limited availability of irrigation water, the inclusion of upland rice in the Mahaweli cropping programs can result in a reduction in the total rice area, and *a fortiori* in the total output of grain.

A particularly cogent argument for the total exclusion of upland rice from Sri Lanka's cropping programs derives from the near certainty that this country will be self-sufficient in rice by 1986. A total physical irrigated area of 489,389 ha will become available by that year. At cropping intensities of 180 per cent for the Mahaweli projects (86,565 ha.) 150 per cent for major schemes elsewhere (234,998 ha) and 110 per cent for minor schemes (167,825 ha), this physical hectarage would provide a crop area of 692,923 ha. At an average yield of 4.1 t/ha, a rice area of 404,634 ha is all that is needed to provide this country's 1986 rice requirements of 1,659,000 tonnes.

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