Oxygen Supply from Shoots to Roots Relative to the Total Oxygen Consumption in Rice Roots

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A new simplified mathematical model was introduced to assess the rate of oxygen supply to plant roots, and to evaluate separately the longitudinal flux through the aerenchymatous system and the transversal flux from the root medium. The parameters were derived from the experimental results with decapitated rice seedlings solution-cultured with aeration. With decreasing oxygen concentration in the root medium, the transversal oxygen flux decreased and the longitudinal flux increased so as to compensate for the decrease of the former, but in some older rice seedlings there was observed a growing insufficiency in oxygen supply to the roots.

It is well known in a rice plant that atmospheric oxygen is transported from its shoot through its continuous aerenchymatous system to its roots. This is considered to be an adaptation to anaerobic soil conditions. Such an oxygen transport has been manifested, though to lesser extent, in some mesophytic plants (Glasstone, 1942; Brown, 1947; Yoshiwara et al., 1953; Greenwood, 1967a, b).

In 1960s, application of $^{18}$O or $^{18}$O revealed that this oxygen transport is a simple physical process by means of molecular diffusion along the gradient of oxygen concentration (Evans and Ebert, 1960; Barber et al., 1962; etc.). The oxygen entering into shoots is received not only by the roots but also by the rooting medium across the root epidermis (Brown, 1947; Kumada, 1948; Yoshiwara et al., 1953; Teal and Kanwisher, 1966; Greenwood, 1967a, b). From an ecological viewpoint Armstrong (1964) compared three species of British bog plants in the rate of oxygen diffusion from roots into rooting medium and suggested that the difference in diffusion rates will reflect similarly graded tolerance of these species to reducing conditions. The transported oxygen is consumed by aerobic respiration of submerged roots and is used for oxidation of such poisonous products as $\text{SH}_4$ at the root surface. It has an essential meaning for a plant to tolerate longer under such anaerobic condition, for intrusion and domination of the plant at the place.

In this paper a simple mathematical model is introduced to estimate the rates of diffusion from shoot and from solution in which rice roots are grown. The model was applied to the oxygen transport in young rice plants to reveal the relative contribution of the oxygen transport through aerial parts and from the root medium.
Theoretical Consideration

Let us take a simple case of oxygen diffusion to the roots. The source of oxygen is confined to the oxygen in soil or in culture solution. This situation is prevalent to species intolerant to the wet soil. We can also assume a similar system in a tolerant rice plant when cutting out its shoot and sealing the cut end. This abnormal system allows us, though only for about an hour, to derive some information on diffusion characteristics.

The transported oxygen is consumed at the respiratory sites in the root system. The rate of diffusion must be balanced with the rate of consumption. For simplicity, we assume existence of a respiratory center in the root system, although actual respiratory sites have to be scattered in the living cells and constitute a broadened oxygen sink. Assuming again that the rate of oxygen consumption at the respiratory center proceeds according to the form of Michaelis-Menten kinetics, we can get the rate of oxygen uptake in a decapitated plant \( F_d, \text{ mg sec}^{-1} \) as follows:

\[
F_d = Q_s(C_s - C) = \frac{bC}{a + C}
\]

The attendant symbols stand for the following meanings:

- \( Q_s \): constant of diffusion from the surface to the respiratory center of the roots (cm\(^2\) sec\(^{-1}\));
- \( C_s \): oxygen concentration in the solution (mg cm\(^{-3}\));
- \( C \): oxygen concentration in the respiratory center (mg cm\(^{-3}\));
- \( a \): \( C \) at which oxygen consumption rate is half the maximum (mg cm\(^{-3}\));
- \( b \): the maximum of \( F_d \) (mg sec\(^{-1}\)).

Elimination of \( C \) from Equation (1) gives

\[
C_s - F_d \left( \frac{1}{Q_s} - \frac{a}{bF_d} \right) = 0
\]

The constants \( Q_s, a \) and \( b \) can be calculated from the measurements of \( F_d \) at different \( C_s \).

Let us now return to an intact rice plant. There are two ways in oxygen transport. The oxygen consumption rate of the root is equal to the sum \( (F_d) \) of the two fluxes; one is the longitudinal flux through the aerial interspace \( (F_r) \) and the other the transversal flux from the root medium \( (F_s) \).

\[
F_d = F_r + F_s = \frac{bC}{a + C}
\]

As in the case of \( F_d \)

\[
F_s = Q_s(C_s - C)
\]

When \( C_s < C \), \( F_s \) has a negative value, and oxygen will diffuse out into the solution. When \( C \) of Equation (4) is substituted to the righthand side of Equation (3), \( F_r \) and \( F_s \) are expressed as a function of \( C_s \) and \( F_r \) by the following equation: