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Effect of Dissolved Oxygen Supply on Seedling Establishment of Water-Sown Rice[1]

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WATER-SEEDING of lowland rice imposes unique environmental conditions for seedling establishment. Inundation conspicuously modifies the exchange of oxygen, carbon dioxide, and other gases among the air, water, and soil and alters the physico-chemical and biological relationships in the soil. Some workers have expressed the view that the dissolved oxygen concentration of the irrigation water at the time of seeding may influence seedling establishment of water-sown rice. As early as 1933, Jones (14) suggested that the poor stand establishment of late-sown rice could be due to a shortage of dissolved oxygen. Recent recommendations by Finfrock and Miller (11) for establishing a crop of rice by seeding into water seem to be based upon the idea of conserving dissolved oxygen in the germination zone. It has been grower experience that for best seedling establishment the seedbed should be as dry as possible before flooding, and that the fields should be sown as soon as flooded. Also running water generally is considered to be more beneficial to the seedling establishment of lowland rice than is stagnant water. Some questions have arisen whether seedling mortality might have occurred because of the low dissolved oxygen status of the water used to irrigate the fields. These observations may, however, be a consequence of changed oxygen-carbon dioxide relationships or may result from removal of harmful metabolites.

Recent studies by Chapman and Peterson (8) indicate, however, that the dissolved oxygen concentration of the flood water is unlikely to limit the establishment of water-sown rice even at water temperatures of 35° C. Their studies showed that when air-dried Stockton clay soil was flooded, the dissolved oxygen concentration of the water decreased only slightly during the first 24 hours. Within 3 days, however, a characteristic diurnal fluctuation in dissolved oxygen developed with maximums exceeding air-saturation. A net increase in dissolved oxygen accompanied the diurnal cycle. The presence of germinating rice seeds in numbers equivalent to field-seeding rates resulted in a substantial initial decrease in dissolved oxygen. There was also a greater diurnal range, and the net dissolved oxygen level ultimately exceeded that in the unplanted control cultures. The latter effect appeared to be related to the increased growth of filamentous green algae in the presence of the rice seedlings.

Dynamic changes in the concentrations of dissolved gases are characteristic of an aquatic environment and arise as a result of fluctuations in the photosynthetic and respiratory activities of the biota. Diurnal fluctuations in dissolved oxygen have been recorded frequently in lakes (19, 4, 7), in rivers (5, 13, 12, 10), in ponds, ditches and swamps (16, 3), and in rice fields (9). The occurrence of dissolved oxygen levels greater than air-saturation is due to the excess of oxygen produced by the photosynthetic activity of algae over the respiration requirements of the biota during the daylight hours (7, 23, 6, 19). Darby (9), in his studies of California rice fields, found that in May the flood water at a depth of 1 foot was "supersaturated" with oxygen from about 7 a.m. to almost 10 p.m., and that at no time during the 24-hour period did the concentration of dissolved oxygen fall below 4 ppm. A peak level of 17 ppm was recorded.

The influence of organic matter incorporated in a flooded soil on the dissolved oxygen concentration of the water has been reported by Patrick and Sturgis (17). They show that fresh clover material added to the soil after a period of flooding brought about the consumption of dissolved oxygen at the rate of 25.0 ppm per hour as compared with 1.18 ppm per hour for flooded air-dried soil.

In view of the uncertainty concerning the supply of dissolved oxygen in the field and its relation to seedling establishment, studies were undertaken to provide information *(1)* on the effect of running water versus stagnant water on dissolved oxygen supply; *(2)* on the effect of the dissolved oxygen concentration of the soil solution at the time of seeding on root penetration; and *(3)* on the degree of reaeration of some well waters used to irrigate rice. The work was conducted in the greenhouse at Davis at the Rice Experiment Station, Biggs, Calif., during 1962.

MATERIALS AND METHODS

Seed and soil—The rice seed used in all pot culture experiments was *Oryza sativa* japonica, cultivar Caloro obtained from foundation stocks of the Rice Experiment Station. Pregerminated seed for water-sowing was prepared by soaking the seed in distilled water at temperatures around 30° C. until the plumule had just begun to emerge. The water was changed at least once during the soaking period.

The soil used was Stockton clay, developed from fine textured basic igneous alluvium and underlain at a depth of 30 to 40 inches by a dark-brown, calcareous clay subsoil.

Running water versus stagnant water studies—Open-air pot culture experiments were conducted at the Rice Experiment Station where a supply of well water with low oxygen concentration was conveniently available. The quality of the water otherwise was good. Fiber glass containers 38 cm. in diameter and 21.5 cm. deep were filled partially with 7.25 kg. of air-dried soil. Six containers were placed in each of 2 shallow, galvanized iron tanks 10 × 2 feet × 7 inches. One of these tanks, used as a hot water bath, was insulated with sheets of fiber glass wool; an electrical heating coil was wrapped around each container to insure good temperature control. The other tank was used as a cold water bath; through it a rapid flow of cold (20° C.) well water was maintained. Each container was carefully filled to a depth of about 14 cm. with 16 liters of well water containing about 3 ppm dissolved oxygen. Stagnant water was maintained in three containers in each water bath, with daily additions being made to replace evaporation losses. In the other containers the water was kept flowing from the water source at such a rate that the total volume was entirely replaced after a certain interval. Replacement rates of 1½, 8, and 24 hours were run in series. In order to avoid movement of the soil and dispersal of the clay in the running water treatments, the water stream was allowed to impinge on the bottom of a small porcelain crucible placed so that its upper edge was level with the surface of the soil in the container. An electrically heated hot water system connected to the same water supply was used to provide water for the high temperature treatment. It was found possible to maintain the temperature of the stagnant and running water treatments within 1 or 2° of each other. A continuous thermographic record was kept of the water temperature in one stagnant water container in each bath, and frequent checks were made daily with a thermometer. Daily temperatures ranged from 18 to 27° C. in the cold water treatments and from 32 to 38° C. in the hot water.

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A population of 133 germinating seeds per container (equivalent to about 200 pounds per acre) was used in the first 2 series; the population was doubled in the third series. The containers were covered each evening so that the seedlings received 12 hours of natural light daily. Dissolved oxygen was determined with a Sargent, Model XV Recording Polarograph, on water samples taken during the first and last hours of daylight.

Root penetration studies—Glass containers 12.5 cm. in diameter and 18 cm. deep, covered on the outside with aluminum foil, were filled partially with 1 kg. of air-dried soil and placed in the greenhouse.

To provide different initial levels of oxygen in the soil solution, deoxygenated water was prepared by bubbling water-pumped nitrogen gas through distilled water for 30 minutes, using a sintered glass aerator. Oxygenated water similarly was prepared by bubbling with commercial oxygen for 30 minutes. The 2 treatments were replicated 6 times. In setting up the experiment the soil was saturated, flooded to a depth of 3 to 4 cm., and the water allowed to stand for 1 hour. Then the surface flood water was siphoned off and the container filled with aerated distilled water to the required depth.

Before the soil was added to each container, a small-bore glass siphon (total volume 1 ml.), painted black to exclude light and fitted with a sintered glass inlet, was clamped permanently in position so that it would be about 5 cm. below the wet soil surface. In this way a sample of water could be drawn off as required and the changes in the dissolved oxygen concentration of the soil solution followed. A similar siphon was installed in such a manner that the inlet was about 2 to 3 mm. below the soil-water interface. The deeper siphons were filled with water as soon as the soil was saturated. After final adjustment of water depth the interface siphons also were filled.

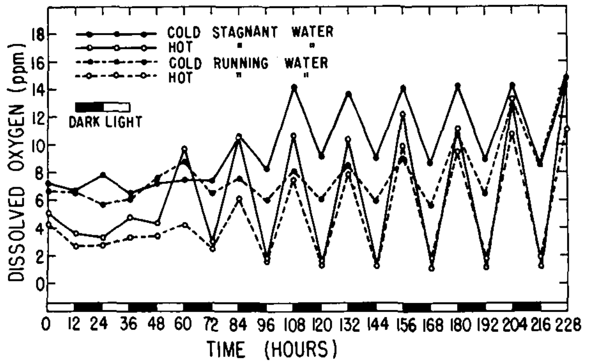

Figure 1—Effect of running versus stagnant water on dissolved oxygen changes in open-air pot cultures under 2 water temperature regimes: 18–27° and 32–38° C. Well water as delivered contained 3 ppm dissolved oxygen. Water replacement rate in the running water cultures was approximately 24 hours. Seedling population was equivalent to 400 pounds of seed per acre.

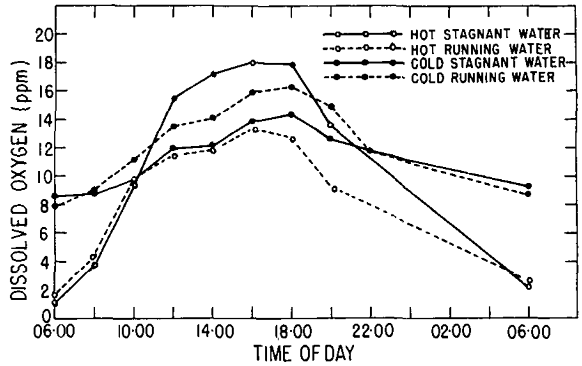

Figure 2—Diurnal dissolved oxygen cycle at first seedling emergence as determined polarographically in open-air pot cultures under 2 water temperature regimes, 18–27° and 32–38° C. Water replacement rate in the running water cultures was approximately 24 hours. Seedling population was equivalent to 400 pounds of seed per acre.

Fifteen pregerminated rice seeds were sown on the surface of the soil in each container. Dissolved oxygen was again measured polarographically using an especially designed microcell requiring only about 0.5 ml. of water for a determination. The samples were collected in 2-ml. plastic squeeze tubes, allowing 2 complete volume displacements, and the measurements were made within 5 minutes.

At "first seedling emergence" (i.e., when the tip of the first seedling emerged through the water), the water was siphoned carefully from each container without disturbing the seedlings. The portions of the root systems remaining above the soil were sprayed with a quick-drying paint. The plants then were removed carefully from the soil, and the lengths of the above- and below-soil portions of the root systems were measured.

Well water studies—Six wells located on 3 properties in the vicinity of the Rice Experiment Station were selected for study. The supply ditches ranged in length from 0 (pump emptying directly into the field) to more than 300 yards, and varied in cross-section from shallow and narrow to wide and deep. All measurements of dissolved oxygen were made at the well sites using the Winkler method (Pomeroy–Kirschman–Alsterberg modification) (2). The determinations were made in duplicate within 2 or 3 minutes after collection of the samples. Wherever possible the water sample was siphoned by means of a rubber tube directly into the standard 300-ml. B.O.D. bottle allowing several volume displacements. Where this procedure was not feasible, a dip sample was taken with a bucket and a subsample quickly siphoned into the B.O.D. bottle. The sampling sites were chosen according to the design of the irrigation supply system.

RESULTS

Effect of running versus stagnant water on dissolved oxygen supply—Figure 1 shows the pattern of dissolved oxygen changes in open-air pot cultures with a seedling population equivalent to twice the recommended seeding rate (i.e., about 400 pounds per acre), and a water replacement rate of about 24 hours in the running water cultures. The dissolved oxygen changes in both stagnant and running water were similar to those found in the laboratory studies of Chapman and Peterson (8). In the stagnant water cultures, after a period during which the concentration of dissolved oxygen showed only a small change, a characteristic diurnal oxygen cycle appeared. At low temperatures the dissolved oxygen concentration of the flood water was approximately the same during the first three days after sowing in both running and stagnant water cultures. Following this period, the average dissolved oxygen concentration of the cold stagnant water increased rapidly, remaining at or about air-saturation for the rest of the experimental period. The diurnal range also remained practically constant. In the running water cultures the rate of increase in the average dissolved oxygen concentration of the flood water was considerably lower and the diurnal range was at first smaller. Subsequently, however, dissolved oxygen reached the same level in both stagnant and running water, and the diurnal range also approached the same value. Dissolved oxygen never was depleted much below 6 ppm in the cold water treatments.

In the hot water treatments dissolved oxygen levels were quite similar in both running and stagnant water during the first 48 hours. Following the development of the diurnal oxygen cycle, minimums of less than 2 ppm occurred after 96 hours. The daytime dissolved oxygen maximums and the diurnal range were consistently greater in the hot stagnant water than in the hot running water. Although at first substantially smaller, the diurnal range in the running water treatment was ultimately of the same order as that in the stagnant water. At the end of the

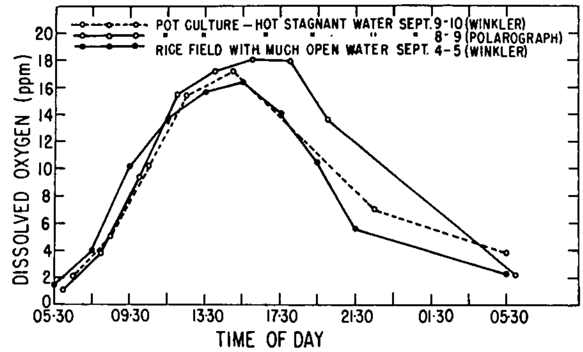

Figure 3—Comparison of the diurnal oxygen cycle at first seedling emergence in a 13-day-old open-air pot culture with that prevailing in a nearby rice field which had been flooded for 4 months. Seedling population in the pot culture was equivalent to 400 pounds of seed per acre. Water temperature, 32–38° C.

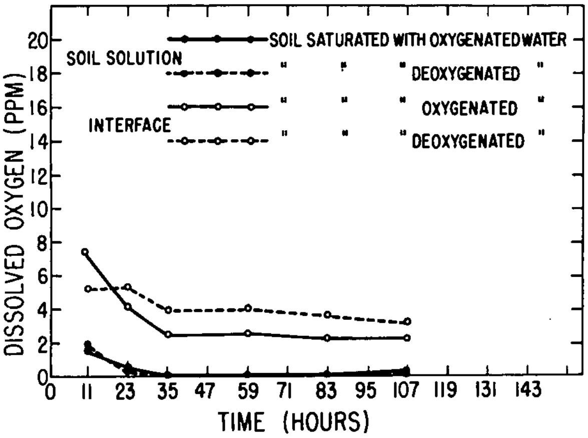

Figure 4—Effect of saturating air-dry Stockton clay soil with oxygenated and deoxygenated water on the changes in dissolved oxygen in the soil solution and near the soil-water interface. Dissolved oxygen determinations made polarographically within 3 to 5 minutes of collection of the water samples.

experimental period, dissolved oxygen maximums were approaching the same value in all cultures.

The development of the diurnal dissolved oxygen cycle was similar at flow rates of 1½ and 8 hours, although apparently modified slightly by algal growth. It was found that the oxygen concentration in the flood water at the time of seeding could be kept low only when the water was replaced at an extremely rapid rate such as once every 1½ hours.

At first seedling emergence the diurnal dissolved oxygen cycle was determined in greater detail for each water treatment; the data are presented in Figure 2. In the cold water treatments the dissolved oxygen concentration of the flood water never fell much below air-saturation (about 8.8 ppm at 22° C.) . Even at high temperatures, the dissolved oxygen concentration of the water was at air-saturation or above for 15 to 17 hours of the day.

The diurnal dissolved oxygen cycle as developed in the hot stagnant water culture was found to be similar, especially during the daylight hours, to that prevailing at the time in a small rice field nearby, which had much open water, large expanses of surface algal mat, and only a trickle of water leaving the outlet box. Figure 3 shows that the diurnal oxygen cycles corresponded very closely, although the determinations were not made on the same day at both locations.

Table 1—Effect of saturating air-dry Stockton clay soil with oxygenated and deoxygenated water on the length of roots of rice plants at first seedling emergence.

Type of water used	Root length per seedling, mm.			% root length above soil surface		
	Primary	Adventitious	Total	Primary	Adventitious	Total
Deoxygenated	74	87	161	7	22	15
Oxygenated	72	90	162	6	21	15

Seedlings were harvested at 8 days. Values are the means of 60 seedlings.

Effect of oxygen concentration on changes in dissolved oxygen in the germination zone following sowing—The effects of saturating air-dry Stockton clay soil with oxygenated and deoxygenated water on the changes in dissolved oxygen in the soil solution and near the soil-water interface are shown in Figure 4. Within 11 hours after sowing (14 hours after flooding) the dissolved oxygen concentration of the soil solution had been depleted to less than 2 ppm; 38 hours after flooding it had been reduced to zero. There was no significant difference between treatments receiving oxygenated or deoxygenated water.

The dissolved oxygen near the soil-water interface, initially higher where the soil was flooded with oxygenated water, remained around 2.5 to 4.4 ppm even after 107 hours. With the exception of the first measurement 14 hours after flooding, the dissolved oxygen level was consistently higher where the soil had been saturated with deoxygenated water. No explanation is offered at present for this difference.

Effect of dissolved oxygen concentration on seedling root penetration—Data on the length of primary and adventitious roots at first seedling emergence are presented in Table 1. Root penetration was found to be independent of the dissolved oxygen concentration of the water used to saturate the soil. Only 15% of the total root length was above the surface of the soil at first seedling emergence. The greater part of this was made up of adventitious roots, one fifth being above the soil, whereas the proportion for the primary root was less than one tenth. The experiment was repeated a second time with similar results.

Oxygen status of some well waters used to irrigate rice—The results obtained from analysis of the well waters show that at the pump outlet the dissolved oxygen concentration of the water was uniformly low, about 0.5 to 1.0 ppm (Table 2). Despite this very low initial oxygen concentration, the water entering the rice fields contained about 5 ppm dissolved oxygen. This means that at a temperature of 20° C. the oxygen concentration was equivalent to more than 50% of air-saturation. Although the method of collecting the water samples was not ideal, there does not seem to be any serious error involved in this instance. The aeration of the water was quite rapid, with the rate apparently being influenced by the design of the stilling pool, the height that the water fell from the pump outlet, and the cross-sectional dimensions of the water stream in the supply ditch.

Calculations showed that for each well tested the mean dissolved oxygen concentration of the water increased by 4.4 ppm between the pump outlet and the rice field. An average of 68% of the oxygen entered the water between the pump outlet and the exit from the stilling pool, as the water foamed and splashed. The values ranged from 43%

at Well No. 1 on the Afton Ranch, where the fall of the water was about 8 inches, to 100% at Well No. 3 on the Lindahl Ranch. Here the water fell about 6 feet onto a concrete slab and foamed and splashed to a height of about 3 feet against a wooden barrier before flowing away at either side.

While the water was in the supply ditch some oxygenation also occurred, apparently as a result of the photosynthetic activity of the phytoplankton growing in the ditch. For the 2 wells where it is valid to make such a calculation (the Gosselin Ranch and the Lindahl Ranch No. 1 Well) the water streams in the supply ditches were of comparable cross-section, shallow and narrow, and of the same order of length. The oxygen taken up by the water while in the supply ditches accounted for about 39 and 34%, respectively, of the total. This may be compared with the Afton Ranch No. 1 Well, where over a comparable length of supply ditch, but where the water was flowing in a broad and deep stream, ditch oxygenation accounted for only about 12% of the total increase in dissolved oxygen.

DISCUSSION

As a consequence of the rapid development of the diurnal dissolved oxygen cycle and its similarity in both running and stagnant water, there seems to be no advantage, from the point of view of oxygen supply, in replacing the water any faster than necessary to make up evaporation and seepage losses. No detailed studies were made of the ecology of the phytoplankton, but observations indicated a close relationship between the diurnal dissolved oxygen cycle and the photosynthetic activity of algae. The photosynthetic activity of organisms growing in association with the rice may produce levels of dissolved oxygen as high as 18 ppm or more than 200% of air-saturation on clear summer days. The similarity of the dissolved oxygen cycle in both pot culture and field is perhaps all the more remarkable when it is considered that the stagnant water pot culture had been flooded for only 13 days while the rice field had been flooded for 4 months. Although minimum levels of dissolved oxygen fell to 2 ppm or less during the night when water temperatures were around 35° C., the oxygen content of the flood water was still at air-saturation or above for 15 to 17 hours of each day. Probably the photosynthetic evolution of oxygen is of considerable significance in the field establishment of water-sown rice, especially since the rapid development of a well-oxygenated layer near the soil-water interface may stimulate primary root elongation.

The oxygen concentration of the flood water used in the pot experiments appeared to be related to water temperature rather than the water replacement rate during the first two days following sowing. It is possible, however, according to Patrick and Sturgis (17), that different results might be obtained where large amounts of fresh organic material are incorporated into the soil. Under these conditions the levels of dissolved oxygen at the soil-water interface may be so low as to interfere with seedling growth and penetration of the primary root into the soil.

The authors have observed instances where excessive elongation of the coleoptile and inhibition of root growth occurred in rice sown in a flooded field following incorporation of a heavy green manure crop. These symptoms are rather typical of those expressed by seedling plants which develop in a low oxygen environment. This situation is sometimes relieved by increasing the flow rate of water through the field. In addition to increasing the dissolved oxygen content which may have been reduced to near zero, the increased flow rate may remove harmful products of anaerobic decomposition.

Table 2—Dissolved oxygen concentration of some well waters used to irrigate rice during the 1962 season in the vicinity of the Rice Experiment Station, Biggs, Calif.

Site and position where sample taken	Date, 1962	O_2 ppm
Property No. 1., W. Gosselin Ranch, East Biggs		
From pump outlet, but before water leaves the pipe (temp. 18° C.)	8/3	1.0
At edge of foaming zone after water falls into head of supply ditch	8/8	3.7
Where water enters pipe near field after flowing in shallow open ditch for about 170 yards.	8/8	5.4
Property No. 2., Afton Ranch, Well No. 1		
From pump outlet, but before water leaves the pipe (temp. 20° C.)	8/13	0.5
As water leaves the stilling pool, beyond the foaming zone	8/13	2.4
From wide, deep supply ditch about 100 yards from pump	8/13	3.0
Property No. 2., Afton Ranch, Well No. 2		
At outlet of stilling pool beyond the foaming zone, after mixing of water from Wells 1 and 2	8/16	3.0
Where mixed water from 3 wells enters field after spreading out into a broad and shallow stream (temp. 20° C.)	8/16	4.9
Property No. 3., W. Lindahl Ranch, Well No. 1		
From pump outlet, but before water leaves the pipe (temp. 18° C.)	8/18	0.6
As water leaves stilling pool, beyond the foaming zone	8/18	3.4
From supply ditch at entry to field; ditch shallow, about 120 yards	8/18	5.0
Property No. 3., Lindahl Ranch, Well No. 3, supplying water directly into field		
From pump outlet, but before water leaves the pipe (temp. 17° C.)	8/29	0.8
Just beyond the foaming zone	8/29	5.2

Instances are known where muddy flood water is used for flooding rice. Muddy water not only restricts the penetration of light into the water-covered plants, but clogs the stomata and reduces the photosynthetic activity of the phytoplankton. Although direct evidence is lacking, the circumstantial evidence appears reasonably good that deficiencies of dissolved oxygen may occur under these conditions.

In the systems studied, the dissolved oxygen concentration of the soil solution was reduced to 0, on the average, within 38 hours after flooding. This depletion rate was slower than that obtained by Scott and Evans (20) in experiments with several clay loams. They found that the soil solution was depleted of oxygen in 6 to 10 hours after flooding of the air-dried soils. It is possible that the above difference could be due to the presence of decomposing organic matter or to high soil or water temperatures. The depletion rate in this study appeared to be independent of the initial oxygen content of the water used to saturate the soil. It should be pointed out that in the preliminary experiments reported here that the flooding of air-dried Stockton clay with deoxygenated water did not reduce the initial dissolved oxygen content of the soil solution. Presumably reaeration occurred by diffusion from air entrapped in the pore spaces during wetting. Similar observations were made by Scott and Evans (20). It is not clear how much importance should be attached to the presence of air entrapped in the soil at the time of flooding. Although the average dissolved oxygen concentration of the soil solution appeared to be unaffected, it is not known how the oxygen status at a particular point was modified. It may be that in the early stages of growth the air entrapped in the soil at the time of flooding is of some significance in root penetration, but that its effects cannot be detected simply by measuring gross changes in the dissolved oxygen of the soil solution, since the critical region is undoubtedly the rhizosphere. Penetration of the soil by the seedling root system appeared to be independent of the average dissolved oxygen content of the soil solution at the time of seeding. This is not surprising in view of the dynamic changes which occur in dissolved oxygen content.

These experiments do not support the conclusion that the degree of aeration of the seedbed, or the dissolved oxygen concentration of the water used to flood the field, influences the establishment of water-sown rice by modifying the dissolved oxygen status of the germination zone. The influence of the oxygenated flood water in a rice field is confined to the upper few millimeters to 1 cm. of the soil. This thin layer is oxidizing with a redox potential of about 0.3 volt, or more, at pH 6. Below the oxidizing zone the soil is in a reductive state with a redox potential of about 0.2 volt, or considerably lower if there is much organic matter present (15, 18).

There is a good deal of evidence indicating that the rhizosphere of a rice plant growing in flooded soil is oxidizing, due at least in part to the transport of oxygen from the aerial parts of the plant through the inter-connecting system of intercellular spaces or lacunae, and its release through the roots (15, 21). The roots of a young seedling of water-sown rice growing in the soil show a distinct reddish-brown color at the soil surface long before the leaf emerges from the water. The question arises as to whether this apparent oxidation of iron in the rhizosphere results from the transport and excretion of oxygen produced by the photosynthetic activity of the seedling or from the movement of oxygen from the surrounding water across the surface of the above-soil roots. Oxygen produced by photosynthesis of the plant did not affect the oxygen content of the root cortex in Van Raalt's (22) experiment; however, he did demonstrate that oxygen can penetrate into the rice root through the outer cell layers. The respiration root mat studied by Alberda (1) must function in this way during the later stages of growth of the plant.

In order for the seedling to become established, the developing roots must pass through the oxidizing layer near the soil-water interface and colonize the reducing zone in which oxygen is absent. On the basis of the above discussion, this should not be very difficult for the plant to accomplish. Nevertheless, it has been observed, particularly during the very early stages of growth of the submerged seedling, that the primary root does not penetrate the soil at all readily but tends to grow along the soil-water interface. This mode of growth is especially marked when water temperatures are high; it is also exhibited by the adventitious roots at a later stage. At first it is difficult to reconcile this behavior of the roots with the above view, especially since he rhizosphere in the vicinity of the root tip is reported also to be strongly oxidizing(15).

A possible explanation is that the rice seedling must rely entirely on its own capacity to supply oxygen to the rhizosphere from the flood water. Following the development of adventitious roots, uptake of oxygen by these roots from the flood water may play a significant role in seedling establishment. This might be particularly true at higher temperatures, when a large proportion of the adventitious root system remains above the soil surface. Probably in the very young seedling the lacunae, which in any case develop at some distance behind the apical meristem, are not very extensive so that oxygen supply is limited. At low temperatures the oxygen demand is also low, and oxygen can be absorbed by the above-soil portion of the roots fast enough to enable effective colonization of the reducing zone. When water temperatures are high, presumably the oxygen demand cannot be satisfied because of the physical limitations to the rate of movement of oxygen from the flood water via the root cortex to the apical meristem. Thus root penetration into the soil might be inhibited.

The concern which has been expressed regarding the possibility of irrigation water being low in dissolved oxygen does not appear well founded. Although the initial dissolved oxygen concentration of many well waters frequently is less than 1 ppm, no evidence was obtained supporting the contention that such waters, by virtue of their low oxygen concentration can reduce seedling establishment in the field. On the contrary, it appears that reaeration takes place in the stilling pool and in the supply ditch so that the water arriving at the field inlet may have an oxygen concentration of more than 50% of air-saturation. Adequate aeration also seems to occur as a consequence of foaming and splashing when well water is pumped directly into the field. Even if partial aeration did not occur in this way, the water soon would be oxygenated by the photosynthetic activity of the phytoplankton. Thus one should be cautious in attributing plant stand reduction in the field to deficiency of dissolved oxygen.

SUMMARY

Pot culture studies were conducted to investigate *(1)* the effect of running versus stagnant water on dissolved oxygen supply to water-sown rice and *(2)* the effect of the dissolved oxygen concentration of the soil solution at the time of sowing on seedling root penetration. Field studies *(3)* to determine the degree of reaeration of well waters between pump outlet and rice field were also conducted.

The diurnal dissolved oxygen cycle characteristic of aquatic environments, in general, was found to be very similar in both running and stagnant water. Dissolved oxygen maximums reached 18 ppm, or more than 200% of air-saturation, while minimums of 2 ppm or less were recorded frequently. At water temperatures around 35° C. the oxygen concentration of the flood water was still at air-saturation or above for 15 to 17 hours of each day. It was found that the diurnal dissolved oxygen cycle occurring in a 13-day-old hot stagnant water culture was remarkably similar to that prevailing in open water in a rice field which had been flooded for 4 months.

Within 38 hours after flooding, the dissolved oxygen concentration of the soil solution was reduced to 0, irrespective of the oxygen concentration of the water used to saturate the soil. The zone near the soil-water interface did not become depleted of oxygen. The length and proportion of the root system remaining above the soil surface at "first seedling emergence", (i.e., when the tip of the first seedling emerged through the water) was not influenced by the oxygen of the water used to saturate the soil.

Dissolved oxygen concentrations of the well waters at the pump outlets ranged from 0.5 to 1 ppm, but by the time the water reached the rice field its oxygen was more than 50% of air-saturation at 20° C. When the water was pumped directly into the field a similar degree of reaeration occurred, probably by gas exchange with the atmosphere during foaming and splashing.

The results are discussed in relation to seedling establishment in the field. It is concluded that plant stand reduc-

tion, due to a deficiency of dissolved oxygen may not be a common phenomenon except perhaps in situations where a green manure crop is incorporated ahead of sowing.

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