877

MASTER COPY

McGRAW-HILL YEARBOOK OF Science & Technology

1995

Comprehensive coverage of recent events and research as compiled by the staff of the McGraw-Hill Encyclopedia of Science & Technology

McGraw-Hill, Inc.
New York San Francisco Washington, D.C. Auckland Bogotá Caracas Lisbon London Madrid Mexico City Milan Montreal New Delhi San Juan Singapore Sydney Tokyo Toronto

McGRAW-HILL YEARBOOK OF SCIENCE & TECHNOLOGY

2 3 4 5 6 7 8 9 0 ML/ML 9 0 9 8 7 6 5

Library of Congress Cataloging in Publication data

McGraw-Hill yearbook of science and technology.
1962- . New York, McGraw-Hill Book Co.

v. illus. 26 cm.
Vols. for 1962- compiled by the staff of the McGraw-Hill encyclopedia of science and technology.
1. Science—Yearbooks. 2. Technology—Yearbooks. 1. McGraw-Hill encyclopedia of science and technology.
Q1.M13 505.8 62-12028

ISBN 0-07-051545-X
ISSN 0076-2016

Soil oxygen

Soil oxygen is contained in soil air. It occupies empty pore spaces in the soil, and it is dissolved in the thin water films that coat soil particles, microorganisms, and the fine roots of higher plants. The term soil aeration refers to the availability of soil oxygen for chemical and biological oxidation in soil.

Respiration pathways. All terrestrial organisms derive energy from substrates in their environments through chemical reactions that require electron acceptors. The biochemical pathways that liberate the most energy per unit of substrate consumed involve chemical reduction of free oxygen (O_2). These pathways are generally referred to as aerobic respiration.

Anaerobic respiration can proceed in soil by adapted organisms, which substitute a variety of alternate electron acceptors [such as the ions nitrate (NO_3^{3-}), ferric iron (Fe^{3+}), manganese (Mn^{4+}), sulfate (SO_4^{2-}), or hydrogen (H^+); and various organic compounds]. These reactions, however, provide energy to organisms much less efficiently than does the reduction of O_2.

Soil micro-, meso-, and macroorganisms, as well as the subterranean members of higher plants, derive the oxygen for aerobic respiration from void spaces in the soil physical matrix. The air in these voids is in dynamic equilibrium with both atmospheric oxygen and the gases expelled by soil organisms as a result of metabolic processes.

Transfer of gases. Atmospheric air is made up of a fairly constant mixture of 21% O_2, 78% nitrogen (N_2), and 1% of all other gases, including about 0.03% carbon dioxide (CO_2). Soil air contains about 78% N_2 as well, but the amount of O_2 is less than 21% and the amount of CO_2 is generally increased by an order of magnitude or more. The elevation of CO_2 content in soil air generally corresponds closely to the depletion of soil-air O_2 content below 21%. As soil air becomes increasingly depleted of oxygen, there is also a tendency for trace-gas by-products of anaerobic processes, such as methane (CH_4), to accumulate as well, but generally at much lower concentrations than CO_2. The result is a continuous gradient for transfer of O_2 from the ambient atmosphere to the soil, and of CO_2 and trace gases from the soil to the ambient atmosphere.

The transfer of gases between soil air and the atmosphere proceeds by a combination of processes, including advective, barometric, diffusional, and thermally driven processes. Overall, the dominant component of gas transfer is diffusion. The short-term influence of the other processes is sometimes large, transferring gas by mass flow either into or out of the soil. Sometimes, nondiffusive processes move gaseous constituents against concentration gradients. Diffusion, however, continuously moves gases along concentration gradients, sometimes slowly, but virtually without interruption or reversal.

There are primarily two physical factors that govern movement of gases between soil and atmosphere and through the soil matrix: concentration gradient, and the characteristics of the diffusion pathway in the soil matrix. The pathway generally varies more than the gradient. The characteristics of the soil diffusion pathway are determined by the total porosity of soil, the size and arrangement of the pores, and the continuity of soil pore spaces. These factors, in turn, can vary because of changes in the physical arrangement of soil solids, or because of alteration of soil pore characteristics through changes in the thickness of water films coating the matrix of soil solids.

Three-phase model. Soil is often described as a three-phase model consisting of solids, soil air, and soil water. Solids usually account for about half the soil volume. This fraction can rise or fall with tillage, compaction, or other sources of rearrangement of pores and solids, such as insect or animal burrowing, freezing and thawing, or settling and reconsolidation with rainfall or flooding. The other half of the soil volume is taken up by voids between solids—the pore spaces. These voids accommodate the oscillating ratio of soil water to soil air. When soil is dried in air, its water content is typically found to be 1–3% by volume. Under normal field conditions the water content fills about half the void space, or about 20–30% of the overall soil volume. Under conditions of flooding, all but a few percent of the void spaces are filled with water; the only exception is small amounts of soil air trapped in some of the pores.

The amount of water in soil pore spaces dominates the availability of soil oxygen for respiration in soil. The reason is that in addition to simply filling space otherwise occupied by soil air, soil water coats soil particles, root hairs, and the various soil biota with thin films. The thickness of these water films is related to the degree of soil wetting (the soil-water potential). Because water is about 10,000 times more resistant than soil air to diffusion of oxygen, the extent and thickness of water films in soil generally governs oxygen availability for soil biota.

The arrangement of soil primary particles into a complex system of pores and water-coated porous aggregates (soil "crumbs") permits simultaneous existence of both aerobic and anaerobic microsites throughout the soil profile. A microsite is a small, isolated domain within the soil matrix that has properties unique to itself by virtue of its static or dynamic properties differing significantly from the rest of the surrounding soil. Sites on exteriors of aggregates can receive oxygen by diffusion through water films readily enough to allow aerobic biological processes to proceed. Deeper within an aggregate, oxygen must diffuse greater distances. Some oxygen is also consumed by microbes along the diffusional pathway to the aggregate interior. Consequently, both aerobic and anaerobic processes generally proceed simultaneously in most soils, as evidenced by the trace-gas enrichment of soil air (compared to the ambient atmosphere), showing elevated amounts of anaerobic by-products in bulk soil air that is otherwise strictly oxidative.

The adequacy of soil-oxygen availability for soil biota depends both on the diffusional availability of soil oxygen and on the metabolic demand for oxygen by soil biota. Although it is often convenient to characterize soil aeration in terms of soil porosity or in terms of the concentration of soil-air oxygen, determining the actual soil-oxygen diffusion rate or an index of soil-oxygen diffusion provides a better estimation of a soil's ability to balance the supply of oxygen against demand.

Soil populations. While soil-water potential is the most important factor affecting the availability of diffusional soil oxygen to internal organismal sinks, the most important factor affecting demand for oxygen is soil (and hence organismal) temperature. Except for warm-blooded mammals, the biomass of the organisms inhabiting soil is in close thermal equilibrium with the soil mass they inhabit. Temperature has a stronger effect on metabolic rate (and hence demand for oxygen) than on the amount of oxygen dissolved in soil water, or the oxygen diffusion coefficients through soil air, or soil water. The aerobic respiration rate of most organisms approximately doubles with each 10°C (18°F) increase in temperature, until temperatures exceed optimal ranges. In contrast, the physical processes affecting supply of oxygen to organisms for respiration generally change only by factors of 1.1 to 1.3 with each 10°C (18°F) temperature change. Thus, soil temperature largely determines if the soil-oxygen supply rate is adequate for respiration or if an oxygen shortage is induced by a demand rate exceeding the supply rate.

Soil organism populations and species change rapidly with changes in O_2 level, redox potential, substrate availability, and water content. Soil bacteria dominate the use of soil oxygen in most situations, and they are the strongest competitors for oxygen among all soil biota, including the roots of higher plants. The demand for soil oxygen by bacteria is dependent on a balance of three key factors: optimal soil-water potential, optimal soil temperature, and abundant substrate for respiration.

Water contents of soil tend to be nearly optimal for most microbial processes when about half the void spaces in the soil volume are filled with water. Optimal temperatures for microbial processes vary considerably depending on the organism, but generally correspond to warm soil temperatures (25–30°C or 77–86°F). Substrates are most abundant when fresh organic matter that can be decomposed is introduced. In natural soils, this introduction involves the decomposition of roots in the soil profile from senescing plants and of litter at the soil surface. In agricultural situations, substrates are often elevated abruptly as crop residues or other organic materials such as animal manure, sewage sludge, or green manure are incorporated into the soil profile with tillage. Soil-oxygen content generally decreases with depth as a result of increasing soil-water content and depletion of oxygen by soil organisms. When soil depth exceeds the active biotic zone, soil-air composition becomes less dynamic. Further changes in soil oxygen with depth then result strictly from physical and chemical processes.

The ability of soil organisms and higher plants to resist or tolerate inadequate soil oxygen levels (hypoxia) varies considerably across species and variety. Physiology, morphology, and associated transitory influences and other soil variables greatly affect organismal survival. They also provide the basis for the complex and multifaceted management of soil-oxygen stress.

For background information *SEE AGRICULTURAL SOIL AND CROP PRACTICES; DIFFUSION; SOIL* in the McGraw-Hill Encyclopedia of Science & Technology.

R. E. Sojka

Bibliography. J. Glinski and W. Stepniewski, *Soil Aeration and Its Role for Plants*, 1985; T. T. Kozlowski (ed.), *Flooding and Plant Growth*, 1984; R. E. Sojka and R. J. Luxmoore (eds.), ASA-CSSA-SSSA Symposium on Recent Research Developments in Plant Responses to the Soil Physical Environment, Denver, October 1991, *Soil Sci.*, 154(4):257–339, 1992.

Sound-transmission system

The commercial introduction of the digital audio compact disk in 1983 raised the audio performance expectations of the public. The significant improvement in audio performance offered by the compact disk has provided an opportunity to market multichannel, premium audio services which deliver compact-disk-quality audio via cable television systems. This article describes a system used to provide a music service that offers 30 or more compact-disk-quality, commercial-and-talk-free audio channels to cable subscribers. Unique to the system are its fully digital transmission and a hand-held remote-control unit with a liquid-crystal display (LCD) which provides song title, composer, artist, and other information to the subscribers. The system includes a 30-channel origination studio, a satellite uplink and receive earth station, cable-headend demultiplexing and modulation equipment, subscriber decoder terminals, and two-way infrared remote-control units with music information displays.

Prior to the introduction of the compact disk in 1983, consumers generally had three media through which they could enjoy high-fidelity audio programming: frequency-modulation (FM) radio, long-playing phonograph records, and analog audio cassettes. By employing 16-bit pulse-code modulation and linear digital-to-analog converters, the compact disk typically outperforms its