Exploring the hidden mysteries beneath our feet –

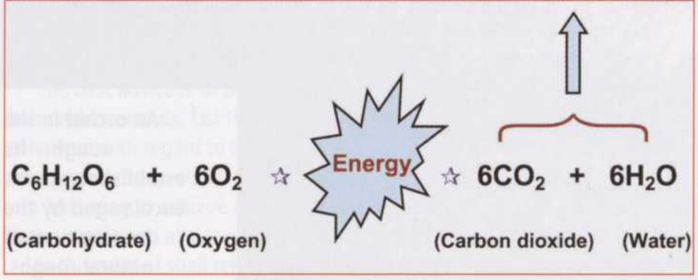
Soil Aeration and the Rooting Environment

Adequate soil aeration is an essential component of any healthy turfgrass stand and is influenced by the physical and biological characteristics of the soil. 'Aeration' as a maintenance practice receives a lot of media attention, while 'aeration' as a soil condition and the phenomena involved are rarely discussed.

Continue to learn

Turfgrass roots and the vast majority of heterotrophic soil microbes, that is micro-organisms that need preformed carbon compounds such as carbohydrates for energy, require oxygen for respiration. In a process similar to our own respiration needs, carbohydrates ($C_6H_{12}O_6$) and oxygen (O_2) are utilised to provide energy for growth and development, giving off carbon dioxide (CO_2) and water (H_2O) as by-products of the chemical reaction.

Figure 1. The Chemical Reactions in Aerobic Respiration



$$C_6H_{12}O_6 + 6O_2 \star \text{Energy} \star 6CO_2 + 6H_2O$$

Respiration will accelerate with rising temperatures, provided that there is no restriction in the input of carbohydrates or oxygen. For efficient respiration by roots and microbes, oxygen must be supplied into the soil atmosphere in adequate amounts, while excess carbon dioxide and other potentially harmful gases must be removed.

The Phenomenon of Diffusion

An exchange of these gases between the soil atmosphere and the outside atmosphere occurs by the phenomenon of diffusion and the aeration status of a soil can be measured by the **Oxygen Diffusion Rate** (ODR). The ODR indicates the rate at which oxygen can be replenished when it is used by respiring roots or micro-organisms. Fortunately, the diffusion rate will also increase as the temperature rises, thereby compensating to some extent for the increased demands by roots and microbes during warmer weather.

Diffusion occurs primarily through soil 'macropores', defined as soil pores that are greater than 75 micrometres (expressed as **'μm'**, and 1000 μm = 1mm) in diameter. As can be seen in Figure 2 below, water will drain from macropores to allow entry of air. Smaller pores will remain full of water because the water is held at tensions greater than gravitational pull. The smaller the diameter of the pore, the greater is the tension at which the water is held.

The efficiency of diffusion is largely reliant on an extensive and continuous network of macropores from the surface and down through the soil. It is essential that the macropore system extends well beyond the rooting depth of the grasses.

Figure 2. Size Classification of Soil Pores and Some Functions of Each Size Class (from Brewer, 1964)

Simplified class	Class	Diameter range (μm)	Characterisitcs and Functions
Macropores	Macropores	> 75	Water drains by gravity, accommodates roots, habitat for certain soil animals.
Micropores	Mesopores	30 - 75	Retain water after drainage, transmit water by capillarity, accommodate fungi and root hairs.
	Micropores	5 - 30	Retain available water, accommodate most bacteria.
	Ultramicropores	0.1 - 5	Retain unavailable water, exclude most micro-organisms
	Cryptopores	< 0.1	Exclude all micro-organisms, too small for large molecules.

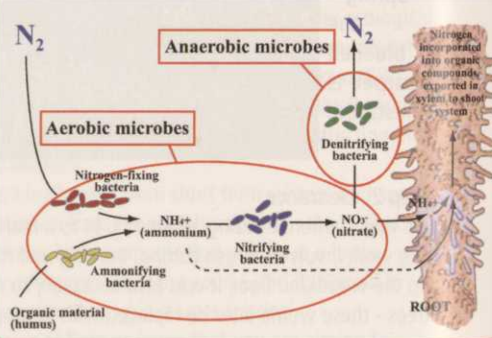
The outside atmosphere contains about 79 per cent Nitrogen (N_2), 21 per cent Oxygen (O_2), and 0.035 per cent Carbon dioxide (CO_2). Concentrations of CO_2 can commonly be 10- to 100-times greater in soil air as a result of respiration of roots and organisms. While the N_2 concentrations in soil air remains much as it is in the outside atmosphere, the O_2 content can vary considerably. It may be only slightly below 20 per cent in the upper layers of a well structured soil but can drop to less than five per cent or even to near-zero in the lower horizons of a poorly drained soil with few macropores.

In well-drained, well-aerated soils in a cool, temperate climate such as Britain, the exchange of gases is normally rapid enough to maintain adequate oxygen levels for plant growth.

Sufficient oxygen can diffuse into the soil, provided the air-filled porosity of the soil exceeds about 10 per cent of the soil volume, for most plants to survive. Generally, turfgrass species are more tolerant of lower oxygen concentrations than the majority of arable crops and decorative plants.

If a soil becomes saturated, diffusion of oxygen virtually ceases and the concentrations can decline to levels that cannot support aerobic metabolism. The soil can become anaerobic (without oxygen) within around 24 hours of saturation. When anaerobic conditions prevail, organisms that can use alternatives to oxygen become highly activated. The first groups of bacteria to have a major influence are those capable of using nitrate (NO_3^-) and denitrification commences (Figure 3 below).

Figure 3. The Role of Soil Bacteria in the Nitrogen Nutrition of Plants



The organisms that carry out this process are commonly present in large numbers and are mostly facultative anaerobic bacteria in genera such as Pseudomonas, Bacillus, Micrococcus and Achromobacter. These organisms are all heterotrophs but some autotrophs (organisms that obtain their energy from sources other than the oxidation of organic compounds) such as Thiobacillus denitrificans, can be involved.

In a series of steps, Nitrates (NO_3^-) that would have been available for plant uptake in an aerobic soil become reduced to Nitrites (NO_2^-), and then to nitrogen gases that include Nitric oxide (NO), Nitrous oxide (N_2O) and Dinitrogen gas (N_2). This is why grasses turn to a pale, sickly green in waterlogged conditions. Contrary to popular belief, nitrites can be taken up by the plants, but cannot be utilised as a source of nitrogen for growth. In fact, the nitrite ion is toxic to plants.

In the presence of organic matter as a food source, other oxidised constituents of a soil will be used and the soil environment will become chemically reduced, as well as anaerobic. As anaerobic conditions continue, oxidised reserves of manganese and iron will be reduced and levels of soluble manganese and iron will increase. Manganese may even reach levels that become toxic. With continuing anaerobiosis, sulphur-reducing bacteria will produce hydrogen sulphide (which is toxic to turfgrass roots) and this will react with the reduced forms of iron to form black ferrous sulphide, the familiar black layer phenomenon of poorly drained golf greens and other sports areas.

Anaerobic conditions will also cause anatomical and morphological adaptations in turfgrasses. Ethylene production in anaerobic soils initiates shallow, adventitious rooting to the detriment of deep, explorative rooting. However, some species display an anatomical response to oxygen deprivation by which the ethylene causes some of the cells in the root cortex to age and die. Enzymatic destruction of the cell walls

Martyn T. Jones, National Turfgrass Foundation, delves into the complexities of soil aeration, its importance, how it occurs and how to preserve it.

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creates air tubes (aerenchyma), thereby increasing root porosity and providing oxygen to the roots. Signs of oxidation in the rhizosphere around some roots can provide visual confirmation of this phenomenon in poorly drained soils.

In well-aerated soils, roots will produce cytokinins and gibberellins but low O_2 levels will inhibit their production and movement through the plant. In contrast, abscisic acid production will increase. The net result is that shoot initiation and growth is suppressed, leaf senescence is accelerated and shallow rooting is encouraged.

What are the causes of poor soil aeration?

Inadequate soil aeration can occur in a number of circumstances. Some, such as severely-compacted, fine-textured soils or flooded environments, are obvious problems. But other occurrences of low aeration status can be less obvious.

There are numerous occasions, even when sufficient total air space is available in the soil, when the exchange of gases between the soil and the outside atmosphere is so slow that an adequate concentration of soil oxygen cannot be maintained.

When things heat up

During hot weather, the demand for soil oxygen by roots and microbes may be greater than the rate at which it can diffuse into the soil. While this most commonly occurs in fine-textured soils or compacted soils, it can occur in non-compacted, coarse-textured soils during periods of very high temperatures.

Traffic, be it pedestrians or vehicles, will compact the surface, reducing the majority of macropores to micropores and, consequently, diminishing oxygen diffusion rates. And the compaction does not need to be to a great depth. Even a relatively thin surface layer of compacted soil can significantly reduce oxygen diffusion rates to the detriment of turfgrass root survival. Indeed, it is frequently a restricted soil aeration condition stemming from a compacted surface, and not a soil drought, which results in turfgrass wilting during periods of high temperatures in the summer months.

The accumulation of organic residues within the soil pores further creates a rootzone dominated by water-filled micropores. Oxygen diffusion through water is ten thousand times slower than it is through air and, therefore, it is little wonder that restricted soil aeration is a common problem of sports soils in the rather wet climate of the UK.

Additionally, under conditions of restricted aeration the organic residues will provide an ideal environment for anaerobic micro-organism activity. Hence the occurrence of black-layer formation within the organic zone or at the interface between the organic zone and the mineral zone beneath.

The surface organic-rich layer, ranging in depth from 80mm to 150mm, depending on the turfgrass species, rootzone material used in the green's construction and maintenance regime is the zone in which there is the greatest demand for oxygen. The highest population of soil organisms occupies this zone and it is the main rooting layer for closely mown turfgrasses.

As a consequence, it is the area in which most respiration occurs and the need for gaseous exchange is greatest. As temperatures rise, and as long as drought does not become a limiting factor, the demand for oxygen by turfgrass roots and soil microbes increases. Therefore it is important that this zone is maintained in an open state throughout the growing season when the demand for oxygen is at its highest. It is far less important during the dormant season when respiration rates are minimal.

The moral to this story is that we must undertake summertime aeration operations when the demand for soil oxygen is at its greatest. It is at this time that the grass roots and the soil microbes are respiring most rapidly and when a good supply of soil oxygen will be most beneficial.

Piercing the organic-rich layer and increasing ODRs will accelerate water infiltration and minimise run-off. It will encourage microbe activity and organic matter decomposition, slowly releasing nutrients (Figure 3 above), improving soil structure and reducing potential disease problems. Keeping the surface open during warm weather is vital in preserving diffusion rates between soil- and outside-atmospheres.

Mechanical aeration versus soil aeration

To ensure adequate soil aeration, it is essential that the number and distribution of macropores are preserved or increased and that there is an uninterrupted network from the surface, down to the full rooting depth. It is the macropore system that provides the means for gaseous exchange between the soil and the outside atmosphere. As an extensive and continuous matrix of macropores is fundamental to efficient soil aeration, any mechanical aeration technique should be directed at preserving the existing macropores and, preferably, creating additional ones.

Selection of the most appropriate and effective mechanical aeration technique must be determined by the soil type, the moisture content of the soil, the extent of the problem, and the mode of action of the equipment. Each piece of equipment has some potential benefits but, equally, each can have detrimental effects if incorrectly applied.

Maintaining an open surface with high water infiltration and oxygen diffusion rates is a prerequisite to good soil aeration but, all too often, the influence of this zone is overlooked. The organic-rich zone in the upper horizons of a soil is where the greatest demand for oxygen occurs. And it is this zone that requires the greatest attention.

As already stated, the main seasons of the year in which there is a demand for oxygen are late spring, early summer and autumn when roots and microbes are most active. Also, there must be adequate aeration during the hot months of summer, provided that drought is not adversely affecting root and microbe metabolism. There is little to no demand for soil aeration during winter when soil temperatures are near freezing and/or when the soil is continuously saturated by daily rainfall. The vast majority of mechanical cultivation techniques will not assist soil drainage at such times.

Regular, light applications of a suitable sandy topdressing material will help preserve the macropore system at the surface and dilute the organic matter content. Timing and quantity is dependent on growth rate of the turfgrasses and extent of organic matter present.

Avoid frequent, heavy irrigation at any time of the year. A saturated soil will have greatly diminished oxygen diffusion rates and will be prone to further compaction.

Achieving effective soil aeration by mechanical means is one of the greatest challenges facing our industry and while we may not witness any major revolution in techniques, evolution in design will bring many improvements.