Dissolved Oxygen in the Greenhouse

White Paper

Dissolved oxygen in irrigation water is vital to plant health. When properly delivered to the root zone, high dissolved oxygen levels can drastically increase a plant's ability to utilize nutrients, defend itself from pathogens, and increase crop yields.

Understanding the important role that dissolved oxygen plays in growing a healthy plant is crucial for the commercial grower.

Dissolved Oxygen in Your Greenhouse

Plants require oxygen to live. Maintaining sufficient dissolved oxygen levels in the irrigation water is the simplest way to increase a plant's overall health.

Elevated dissolved oxygen levels improves the resistance of plants to stress caused by diseases, poor irrigation regimes, and feeding and climatic conditions. It increases nutrient uptake and conversion efficiency. This enhances the growth and development of roots, vegetative and flowering characteristics. The benefits apply in the cultivation of vegetables, herbs, bulbs, ornamentals, cut flowers and arboriculture.

Appropriate levels are also particularly effective in reducing the threat from various opportunistic pathogens, by reducing plant stress and improving plant vigor and resistance.

The intent of this paper is to provide a fundamental understanding of what dissolved oxygen is, why it is of vital importance to plant health, what levels of dissolved oxygen are necessary and desired, and how it can best be produced and utilized in a commercial growing operation.

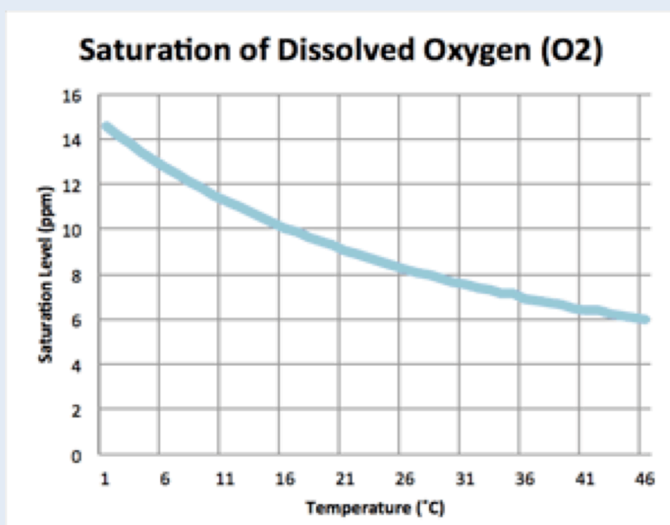
What Is Dissolved Oxygen?

Dissolved oxygen, DO, is simply the amount of oxygen (O2) dissolved in water. It is one of the best indicators of the quality, and the life supporting ability, of water. People need the right amount of oxygen in the atmosphere to survive. And, just as fish need the right amount of dissolved oxygen in the water to survive and thrive, so too, do plants.

DO Saturation Levels at Various Temperatures

For reference, a common tap water source might have between 5-7 ppm, and water straight from a well may be as low as 0.5-2.5 ppm.

DO Saturation Levels vs. Temperature



Measured in mg/l, as a percent of saturation (%), or in parts per million (ppm), dissolved oxygen (DO) levels are affected by the **temperature** and salinity of the water and also by other chemical and/or biological demands (COD/BOD) of the water. Cold water can hold more dissolved oxygen than warm water, and fresh water can hold more dissolved oxygen than salt water. The maximum amount of DO that the water can hold is called the saturation value. **It is possible, and very often desired, especially in a greenhouse, to exceed the natural saturation point of DO in water.** This is called super-saturation.

Dissolved oxygen can enter bodies of water naturally, typically at the surface of the water where exchange between the atmosphere and the water takes place. In nature, waves and wind help increase surface exposure to allow more oxygen exchange and increase oxygen into the water.

In the commercial greenhouse, however, there may not be any opportunity to naturally or easily increase the DO and there are many chemical and biological oxygen demands in the water and piping to reduce the DO levels. It becomes the grower's responsibility to be aware of, and if necessary, take steps to increase the levels by other means.

It's very important to remember these temperature effects when trying to control the DO rates to your crop. The effects of higher DO can be so beneficial to plant health and production that if other methods of boosting DO levels are not used it is very often worth investing in chillers to cool the irrigation water, thereby allowing the water to hold more DO for a longer amount of time.

Dissolved Oxygen Meter

At levels above 5 mg/l of dissolved oxygen, irrigation water is typically considered marginally acceptable for plant health. *Most greenhouse crops, however, will perform better and better with higher levels. Levels of 8 mg/l or higher are generally considered to be good for greenhouse production and much higher levels, as high as 30 mg/l or more are achievable and can be beneficial.* If the DO levels are below 4 mg/l, the water is hypoxic and becomes very detrimental, possibly fatal, to plants and animals. If there is a severe lack of DO, below around 0.5 mg/l, the water is anoxic. No plants or animals can survive in anoxic conditions. *The irrigation water in many greenhouses has surprisingly low levels – often in the dangerous hypoxic range.*

Why Is Dissolved Oxygen Important To Plants?

Healthy roots. Everyone knows that carbon dioxide is required by plants for photosynthesis – that green plants convert light energy to chemical energy (sugars). **Plants also require oxygen to survive.** It is an essential element. The root system requires oxygen for aerobic respiration, an essential process that releases the energy required for healthy root growth and a healthy plant.

Research shows that higher dissolved oxygen levels in the root zone of most crops results in a higher root mass[1]. A plant with more root mass grows healthier and faster. A plant's roots are where it gets the majority of its inputs for growth, including water and nutrients. Healthy roots with a good supply of oxygen have better respiration and are able to selectively absorb more ions in solution, such as the vital mineral salts nitrogen, phosphorus and potassium.[2] *When there is less oxygen in the water than there is in the plant this reduces the permeability of roots to water therefore reducing (even reversing) the absorption of nutrients.*

Good vs. bad bacteria. A plant's roots need **beneficial bacteria** present at the root zone. Beneficial bacteria thrive in an oxygen rich environment – harmful bacteria do not. By increasing the DO levels in the root zone, we promote these good bacteria and their reproduction while creating a hostile environment and therefore excluding harmful bacteria, also referred to as competitive exclusion. Research continues to show that there is a direct correlation between the amount of beneficial, oxygen-loving bacteria around the roots and the overall health of a plant.

A root zone without oxygen is anaerobic. Harmful bacteria and diseases become more prevalent in an anaerobic environment. At the same time, the plant becomes more susceptible to these harmful bacteria and disease. Think of humans... If we do not eat right and take care of our bodies, our immune system becomes weaker and our ability to naturally fend off harmful bacteria, viruses and diseases is reduced. It's the same for plants. Case in point, a common fungus found in greenhouse operations, pythium, is a well-known opportunistic pathogen – one that is nearly always present. This virus, in essence, waits for a plant to become vulnerable. It's usually only once a plant's immune system is suppressed that the pythium becomes harmful. *Without appropriate DO levels; the plant cannot take up the right amounts of nutrients, is more affected by sub-optimal environmental conditions (temperature, humidity, light) and becomes stressed.*

Also becoming better understood is the fact that elevated dissolved oxygen levels within the root zone **increases the salt tolerance** of most plants. Research indicates that this occurs without the loss of dry weight, root mass or production - very significant findings.

Farmers have known for years that proper soil techniques, such as tilling, **improve the perking ability of soil**. More oxygen present at the soil surface reduces the "bio-fouling" of the soil, increasing the available airspace, allowing deeper penetration of oxygen. Greenhouse growers also know that properly aerated soil prevents oxygen deprivation, allowing for deeper, healthier root structures. For soilless medias and hydroponically grown greenhouse crops, dissolved oxygen plays a huge roll in improving plant health and increasing yields.

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1 ISHS, W. Holtman, B. van Duijn, A. Blaakmeer, C. Blok – "Optimalization of Oxygen Levels in Root Systems as Effective Cultivation Tool"
2 LIDA Plant Research – "Oxygenation of roots as a method of disease prevention"

Why Is Dissolved Oxygen Important to Greenhouse Growers?

A healthier plant is a more efficient plant. DO isn't just an additional nutrient one should pay more attention to because it makes a healthier plant; there are direct economic impacts, as well. When used properly, it can reduce the amount of nutrients and micronutrients required, as well as the amount of costly chemicals, such as fungicides. Additionally, evidence suggests that plant growth increases with super-saturation levels of DO, reducing cropping times and increasing fruiting or flowering yields.

Studies are finding that DO plays a role in increasing the shelf life of products, such as cut flowers, bulbs and produce.

Most growers know that soil/media aeration is beneficial to their nutrient solutions and ensure that their medias are not compacted and maintain good porosity. **However, few pay as much attention to the irrigation water and maintaining the appropriate DO levels to the root zone of their plants.** By not attending to DO levels in the irrigation water, their plants are unable to fully utilize the expensive fertilizers present in the nutrient solution and are more susceptible to disease, pest infestations and less robust growth.

Clean pipes. The irrigation distribution system in a greenhouse environment has always been considered the necessary evil. Of course we need to get the water and nutrients to the plants, but these same pipes that are so crucial to a plant's survival may also be harboring and delivering pathogens via the well documented existence of **biofilm**[3]. It is known that irrigation water with high dissolved oxygen levels is far superior in maintaining clean pipes than water with low levels.

Good growers know that maintaining good hygiene throughout their irrigation system is a key to producing healthy plants.

How do we measure DO levels?

- Meters and Probes
  - Hand held DO meters are becoming very good, easy to use and less expensive
  - Affordable, from $500 to $1,500
  - Nearly instant readings
  - Can be placed in varying water depths utilizing longer cables
- Field Kit – The Winkler Method
  - A sample bottle of water is collected, then using a series of reagents, the DO is fixed and can be accurately estimated
  - Inexpensive - $35-200 for around 50-100 tests

[3] For more on biofilm in the greenhouse, download our whitepaper on the topic, available at http://www.dramm.com/.

Getting Dissolved Oxygen to the Plant

One reason that DO remains relatively untested and misunderstood in greenhouses is that increasing dissolved oxygen in irrigation water is not as simple as adjusting pH or EC.

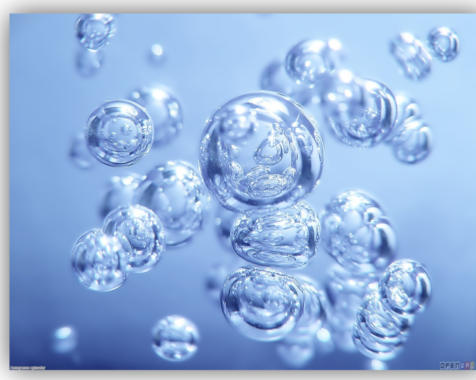
Putting DO in the irrigation water can be done in a number of ways. It is first very important to understand the term **oxygen demand**. We must be able to first meet the oxygen demand within an environment (in this case, an operation's complete irrigation system), before we can think about supplying the plant, in particular, the root zone, with a helpful amount of DO. An operation's irrigation distribution system, (it's tanks, piping, emitters, etc.) must be free of oxygen demanding substances, such as biofilm and organic matter, before controlled DO levels can be delivered. It is generally accepted that a DO level of **at least** 6mg/l (or 6 ppm) is desired at the root zone of nearly every plant grown.

Whether an operation's water source is municipal, out of a well, or from a pond or stream, (or any combination of these), a good grower should be aware of everything that might deplete the irrigation water of valuable oxygen.

Methods of Getting Dissolved Oxygen in Solution:

1. **Hydrogen Peroxide**: Probably the most misunderstood method, hydrogen peroxide (H_2O_2) is often thought to add to the DO levels in irrigation water. This is only somewhat true. Once the important difference between O_2 and O_2^- is understood, it becomes clear that this method may not be the best choice for efficiently increasing an irrigation water supply's DO. When put into water, H_2O_2 converts to H_2O and O_2^-. O_2^- is the free radical form and indiscriminately oxidizes everything, including healthy plant cells[4] – we don't want this one. O_2 is the diatomic form of oxygen and is readily absorbed by a plant's roots – this one we want. H_2O_2 is best left as the cleaning and disinfection tool it is traditionally known for in horticulture.

2. **Air Pumps with Air Stones or Diffusers**: Many growers try using different bubblers, or diffusers in their irrigation storage tanks to try to increase the dissolved oxygen. The combination of an air pump and some type of air stone is the most common. This might work relatively well for keeping a fertigation solution well mixed, but it can be difficult to get the levels of DO needed. The best methods are the ones that make the highest amount of the smallest possible bubble. Smaller bubbles are less buoyant; therefore travel slower to the surface, allowing more



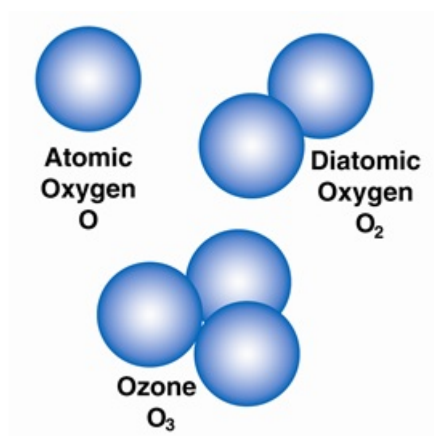
[4] "Airing Out the Truth on Dissolved Oxygen"

time to exchange with the water. Smaller bubbles also have a greater surface area relative to their volume, also very important for maximum diffusion of oxygen into the water.

It should be cautioned, however, compressors with simple air stones and some other types of diffusers, if not properly designed and installed, could actually exacerbate the very problem trying to be solved. Remember that warmer water holds less oxygen than colder water. Often, air pumps and compressors will heat up, especially when the output is restricted, heating the air they pump. This can cause the water to heat up, reducing the saturation level of DO.

3. **Air or Oxygen Gas injection:** This method is an effective although limited approach to getting oxygen into water. It employs a simple venturi injector to draw in oxygen (either atmospheric or from an oxygen concentrator) and inject it into a side stream of water passing through the injector. If this is done with atmospheric air (e.g. pulled from the room in which the injector is located) the results are limited to the oxygen content of air, generally around 20.95% in dry air, and Henry's law. Feeding about 98% pure oxygen into the injector from an oxygen concentrator can boost the results. Oxygen concentrators, just like the one's used in hospitals and care facilities, remove the approximately 78% nitrogen and some moisture from the air, leaving mostly (about 98%) oxygen and a small trace of argon and CO2. The results of this are, of course, still subject to Henry's Law, which states that, depending on the temperature of the water and several other factors, the DO levels will not likely exceed perhaps 8 or 10ppm in best conditions - good but not the best achievable.

4. **Ozone**: Ozone is O3. O3 is created by breaking up regular diatomic molecules (O2) with an electrical charge, where they reform as triatomic molecules (O3), also known as ozone.



O3 is up to 13 times more soluble in water than pure O2 and it is very unstable so it quickly converts back into O2. Since we can "stuff" up to 13 times more O3 into the water than O2, this results in super-saturation of the water with O2, after the O3 converts back to O2. Henry's Law, identifies the solubility of a given gas in a given liquid, and "dictates" that the maximum level of O2 in water, even at very low temperatures, tops out at 14.5 ppm of O2 into solution, or 14.5 ppm DO. As water temperatures increase DO levels will decrease. Chemical and biological oxygen demands, such as biofilm, reduce DO levels further. That is why most irrigation water is limited to 5 to 10ppm of DO without the use of ozone or liquid or chemical oxygen.

The most effective way of introducing the highest possible levels of DO into water, ozonation, is becoming more and more common in the greenhouse. Ozone is produced on site from ambient air and is increasingly used for irrigation water disinfection. A key reason for ozone use in horticulture is that once the ozone (O_3) has oxidized (destroyed) the pathogen, biofilm or bad bacteria, it converts to DO. The ozonation process allows about 12.5 times more DO to be put into solution than using pure oxygen. [5]

Practices that Decrease Available Dissolved Oxygen

Overwatering

Can decrease oxygen levels as it makes growth media less porous. If the dissolved oxygen level outside the roots is lower than inside the roots, they can actually lose DO.

Higher Irrigation Water Temperature

The warmer the water, the less dissolved oxygen it can hold. Also, higher temperatures can stress crops.

Over fertilization

The higher the salt content in the media, the less dissolved oxygen it can hold. F

Biofilm

Allowing biofilm to accumulate in piping systems will increase the demand on DO, reducing it.

[6]

Once valuable dissolved oxygen is present in irrigation water, keeping it in solution for as long as possible is important – Maintaining cooler water temperatures and the proper stirring of storage tanks are two common practices.

In Conclusion

Understanding dissolved oxygen is important to the greenhouse operator in producing a healthy plant. Unlike the more focused upon water properties of pH and EC, DO has not gotten the attention it deserves, but that is changing. More and more research is proving that a high dissolved oxygen level delivered to a plant's roots is very beneficial to a plant's overall health and growth.

Readily available technologies, such as ozonation, allow for more efficient, economical and controllable dissolved oxygen deliverability within the commercial greenhouse environment.

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[5] For more on Biofilm in irrigation systems, download our whitepaper: Biofilm in the Greenhouse available at www.dramm.com.

[6] Fieldhouse, Robert. University of Guelph – "Higher Dissolved Oxygen Could Boost Productivity for Greenhouse Growers"