Oxygen: Plants Cannot Survive Without It

By Youbin Zheng, Thomas Graham and Mike Dixon
Controlled Environment Systems Research Facility, University of Guelph

Oxygen is Essential for Achieving a Healthy Hydroponic Crop

Plants, just like us, cannot survive without oxygen (O_2). Plants produce O_2 by photosynthesis and need O_2 for respiration. Respiration is essential for releasing the energy from photosynthates, and producing the carbon backbones used for plant growth and metabolism. For example, root respiration, which provides the driving force for root growth, maintenance and nutrient absorption, is reliant on root zone oxygen. In the absence of adequate dissolved oxygen (DO) in the hydroponic solution, none of the aforementioned processes can occur, leaving the plant in a vulnerable state. A well oxygenated root zone, therefore, is essential for a healthy root system (nutrient uptake and root growth/maintenance), and the prevention of root borne diseases. For example, Shérif and colleagues (1997), conducted an experiment in which they grew tomato plants in solution culture under various levels of solution oxygenation. They then inoculated some of these plants with *pythium*. The results showed that for the well aerated plants, both roots and shoots, were much larger than those plants that had received the low DO treatment. Non-aerated plants started to show signs of root browning and infection within 6 days of being inoculated with *pythium*, while the well aerated plants remained healthy throughout the experiment.

Propagation of plants, via cuttings, is also impacted by the levels of oxygen available in the root zone. It has been shown that one can improve root formation in cuttings by diffusing oxygen through the rooting media, as compared to non-aerated cutting propagation.

What Is the Optimum O_2 Level in Root Zone Nutrient Solution?

The Earth's atmosphere is composed of 21% O_2 and 78% of nitrogen (N_2), with the remaining 1% being various trace gases. Root zone O_2 is present in two forms, gaseous O_2 in the voids of the growth media and DO in the nutrient solution. Gaseous O_2 concentration is influenced mainly by growth media air porosity, diffusion rate of O_2 from the atmosphere to the root zone, root O_2 consumption rates and the watering frequency. DO concentration in the root zone nutrient solution is mainly controlled by factors such as temperature, partial atmospheric O_2 pressure and salt concentrations, among other factors. Temperature is the most important factor, as it most dramatically impacts the oxygen holding capacity of a solution. For example, an increase in temperature from 20 to 30°C, reduces the DO concentration of air-saturated water from 9.1 to 7.5 mg/L (see table 1). Table 1 gives the saturated DO levels of fresh water at different temperatures and under normal atmospheric conditions (21% O_2). However, new technologies are able to enrich nutrient solutions with DO to levels much higher than the saturation level. For example, a commercial oxygen diffuser (Seair Diffusing Systems Inc, Edmonton, Alberta) has been demonstrated to bring the DO to 40 mg/L in nutrient solutions under normal greenhouse conditions.

Table 1. Oxygen solubility in fresh water at different temperature when the atmospheric O_2 is 21%.

Temp (°C)	5	10	15	20	22	24	25	26	28	30	35
DO (mg/L)	12.8	11.3	10.1	9.1	8.7	8.4	8.2	8.1	7.8	7.5	6.9

Now, logically, you may ask the following questions?

1. What is the optimum nutrient solution DO level?

The answer cannot yet be definitive as there are insufficient research studies in the literature. Most of the research to date has only looked at saturation or sub-saturation oxygen levels, ignoring the super saturation levels now available with appropriate technology. It is suggested from the existing literature however, that maintaining at least normal oxygen saturation produces the best results, with significant decreases occurring at levels below 25-30% DO saturation. Further research is required to determine whether DO concentrations above saturation improve productivity beyond that of typical DO saturated conditions.

2. Is there any negative effect on crops as a result of using nutrient solutions at supersaturated oxygen levels?

The long and short of this question is that we don't know. Very little research has addressed the subject of using oxygen supersaturated solutions for plant production. The few studies that are available have conflicting results, with negative, neutral and positive effects all being reported. More extensive greenhouse research is needed to investigate the physiology, growth and yield responses of crops to nutrient solution oxygen enrichment. Presently, our research group, at the University of Guelph, is conducting exploratory research on this issue, including an eventual cost/benefit analysis of root zone oxygen enrichment. We hope to expand the scope of these initial studies to explore the numerous aspects and applications of nutrient solution oxygen enrichment. Clearly, as the technologies emerge for supersaturating nutrient solutions with O_2, so too must the research that answers these fundamental, yet unanswered questions.

Ways to Increase Root Zone Oxygen Concentration and Considerations

1. Atmospheric oxygen

The easiest and most common way to boost DO is to bubble air through the nutrient solution. This method may not be sufficient for some of the media and watering regime combinations presently used, especially during the summer months when temperatures are highest and the DO saturation points are at their lowest. In addition to lower DO concentrations, some media, such as old sawdust, does not have the porosity required to offset the lower DO with diffusion of gaseous oxygen. Initially, sawdust has good structure and porosity for aeration. Over the course of the growing season, the sawdust degrades, causing a reduction in porosity, which under high watering frequency, results in limited gaseous oxygen in the plant root zone. In this circumstance, even the use of well aerated solutions may be insufficient to prevent root zone oxygen deprivation.

2. Pure oxygen

To address the problem with aeration in degraded and compacted substrates, pure oxygen can be used to either supersaturate the nutrient solution or it can be directly injected into the growing media (not economically feasible under typical conditions). There are some oxygen diffusing techniques which can be employed to super saturate nutrient solutions. However, as mentioned earlier, we are still unsure of all the effects of using supersaturated solutions in traditional production systems

3. Ozone

Ozone (O_3) is made up of 3 oxygen atoms. It is a very strong oxidant, and as such is commonly used as a purification and disinfecting agent. An ozone residual level of 0.4 ppm for 4 minutes has been shown to kill most commonly occurring bacteria, viruses, moulds and fungi that may be present in a nutrient solution. Ozone decomposition (eg: oxidation of contaminants) reactions can release oxygen (O_2), hydrogen peroxide (H_2O_2), and hydroxyl radicals (OH^-). Both hydrogen peroxide and hydroxyl radicals can kill disease causing microorganisms in hydroponic systems. Ozone can also act directly on microorganisms causing a rapid cellular lysis (destruction), resulting in reduced levels of microorganisms, including disease causing microbes. Ozone, however, would have the same effect on plant roots should it accumulate in the root zone. As such, residual (what is left after all the microbes and organics have been consumed) ozone mush be reverted back to O_2, which has the benefit of further enhancing the DO content of the post treatment nutrient solution.. At present, our group (Controlled Environment Systems Research Facility, U. of Guelph) is conducting research on the use of ozone to control pathogenic microorganisms in nutrient solutions, while maintaining good aeration through ozone oxidation reactions. The anticipated results will provide us with a practical protocol for nutrient solution ozonation and oxygenation.

4. Hydrogen Peroxide

Hydrogen peroxide solution is clear and colourless just like water. It can be dissolved into water in any proportion. Hydrogen peroxide can be used for deodorizing and disease control. Decomposition of hydrogen peroxide during the oxidation of contaminants in a nutrient solution liberates an oxygen molecule (O_2). As with ozone, H_2O_2 is a very strong oxidant, and at too high of a concentration, it can damage hardware and have negative impacts on your crop. The critical concentration, above which negative effects will occur, is crop and medium dependent as are many of the techniques we have discussed.

Conclusions

Oxygen is essential for a healthy and productive hydroponic crop. Root zone oxygen deficiency can cause plant wilting, retard plant growth and increase the susceptibility of roots to disease establishment. Oxygen deficiency is most likely to occur during the summer months, when temperatures are at their greatest, especially when combined with low air porosity growth media and a high watering frequencies. Growers should monitor their root zone oxygen levels to ensure that the oxygen levels in the root zone do not fall below 25-30% of the saturation level (see table 1). Modern technologies can supersaturate nutrient solutions with oxygen; however, the impacts of this practice have yet to be clarified through dedicated scientific studies. Ozone and hydrogen peroxide can be used to control diseases, while providing a potential source for supplemental nutrient solution oxygenation. Caution should be taken when applying these two chemicals in your greenhouse, as there are worker safety and plant application issues that should be understood prior to utilization of these technologies.

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Dr. Youbin Zheng, Tom Graham and Dr. Mike Dixon are researchers at the University of Guelph. Their main research interests are advanced life support and greenhouse crop production. Dr. Zheng can be reached at (519)824-4120X52741 or yzheng@uoguelph.ca.

Effect of Oxygenated Water On the Growth and Biomass Development of Seedless Cucumbers and Tomato Seedlings under Greenhouse Conditions.

Mohyuddin Mirza, Ph.D., P.Ag.
Greenhouse Industry Development Specialist and
Wanyu Chen, Research Technologist
Crop Diversification Centre North,
Alberta Agriculture, Food and Rural Development
RR6, Edmonton, Alberta, Canada T5B 4K3

Introduction:

Dissolved oxygen in irrigation water affects the root zone environment in many ways in greenhouse crops. Most of the greenhouse vegetables in Alberta and Canada are grown in hydroponics systems with or without the use of a growing medium. The growing volume is generally limited to a few liters/plant to make the use of greenhouse space in an economic manner. For example 3 cucumber plants are grown in a 20 L pillow bags with sawdust or coir (coco fiber) as a growing medium. Two plants are grown in 20 L buckets, which provide better vertical drainage. Tomatoes are grown on smaller volume of growing medium. The growing medium volume affects the oxygen and water dynamics in the root zone and the plant growth and yields can be affected by the amount of oxygen in water.

For example oxygen in water at 4C is generally around 8-10 ppm if there is not high biological activity. In many dugouts water supply we have observed oxygen as low as 4 ppm because of high microbial activity. When this water is used to irrigate plants, the oxygen in leached water may be as low as 1-2 ppm. Such low oxygen promotes the growth of pathogenic fungi like *Pythium* which attacks root hair and thus reduced the plant's capability to absorb water causing water stress and thus reducing yields. Furthermore low oxygen in root zone promotes an increase of gases like carbon di oxide and other gases, which are bye products of root respiration.

Oxygen demand in inorganic mineral growing media consists of root and microbial respiration. Root respiration provides plants with energy for root growth, ion uptake and maintenance processes, and is influenced by among others, temperature and relative growth rate (Van der Werf 1993). Oxygen availability to roots grown in soilless culture can become limiting in case oxygen demand exceeds oxygen supply, inducing reduced root growth rate, ion and water uptake, eventually reducing production (Pezeshki et al. 1993).

Thus increasing the dissolved oxygen levels in water especially at higher temperature e.g. 20C, should be beneficial to root zone. Following advantages may be expected:

- Better root health, which will promote better absorption of nutrients.
- Reduced incidence of diseases like *Pythium* damping off , which is a low oxygen disease.
- Better plant quality
- Better and higher total marketable yields

This is the first part of a larger study to determine the beneficial effects of dissolved oxygen in water on the growth and biomass development of cucumber and tomato seedlings grown in rockwool cubes and coir.

Material and Methods:

A research study was conducted between January and March 2003 at the Crop Diversification Centre North, Edmonton, Alberta, Canada in which the affect of using oxygenated water and regular city of Edmonton water was studied on the growth of seedless cucumbers and tomatoes. Cucumber CV Corona was seeded in 2.5 cm rockwool cubes and germinated at 24C. After 2 weeks the seedlings were either transferred into 15 cm rockwool blocks or 15 cm green, plastic pots with pre-wetted coir as a growing medium. Tomato seeds CV Blitz were similarly germinated in 2.5 cm rockwool cubes and after 3 weeks the seedlings were transferred either into 15 cm rockwool blocks or 15 cm green plastic pots containing pre wetter coir.

The seedlings were grown for a period of 5 weeks in case of cucumbers and 6 weeks for tomatoes in a replicated, completely randomized factorial design. There were four replicates of 10 plants each. There were two treatments compared in this study. Water was oxygenated using SEAIR Diffusion System, 3LPM generator. Non-oxygenated water came from city of Edmonton water supply.

Treatment of seeds with two types of water was started right at the time of germination and continued till the end of the experiment. Oxygenated water was always over 20ppm and regular water was around 12.8 ppm at a temperature of 14C.
The plants were regularly fertilized with a nutrient solution of the following composition:

Nitrogen 200 mg/L, Phosphorus 40, Potassium 350, Calcium 150, Magnesium 60, Sulfur 120, Iron 3, Manganese 0.8, Copper 0.15, Zinc 0.12, Boron 0.25 and molybdenum 0.10. The nutrients were derived from commercial fertilizers. The plants were watered as needed. PH was maintained between 5.8 and 6.2 and Electrical Conductivity (E.C.) was maintained between 1.5 and 2.0 ms/cm.

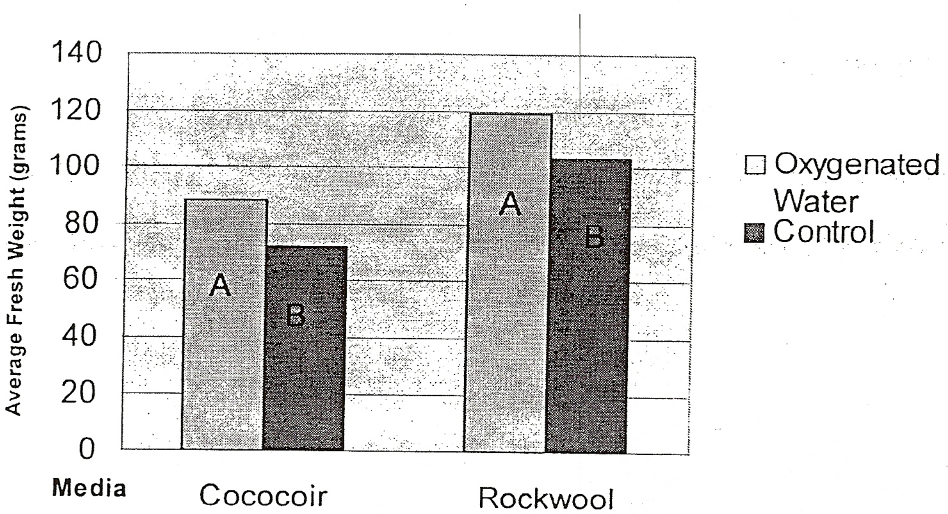
At the end of the experiment the plants were cut off at the base and fresh and dry weights were determined. Roots weights were difficult to quantify because a significant number of roots were inside the growing medium and could not be removed for weight determination.

The statistical data was analyzed using Duncan Multiple Range Analysis using SAS program.

Results:

The following graph presents the comparison of two treatments on fresh biomass of 5 weeks old cucumber seedlings. The seedlings which were grown on non-oxygenated water in coir had a fresh biomass of 72.0 grams as compared to 88.20 grams weight obtained in seedlings grown in oxygenated water. Similarly, the fresh weights were 103.27 and 119.37 grams for seedlings grown in rockwool for the respective treatments. The weight differences were statistically significant at 0.05% level of probability.

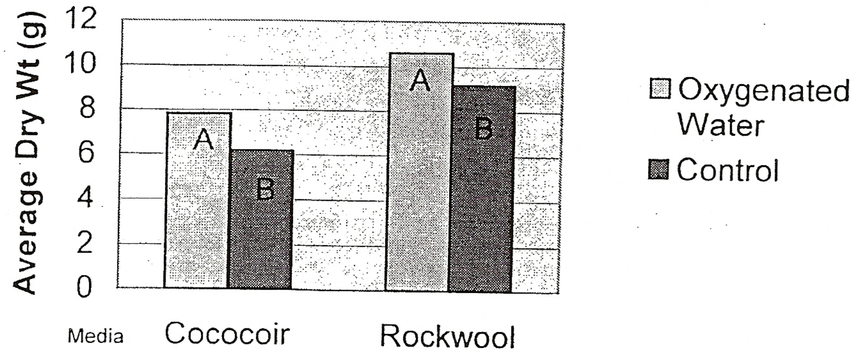
Effect of Oxygenated Water on the Fresh Biomass of cucumber seedlings.



Different letters in bars indicate significant differences at 0.05% level of probability

The graph below presents average dry weights of cucumber seedlings grown on non-oxygenated and oxygenated water treatments. It was 6.17 grams in seedlings grown in non-oxygenated water in coir and 7.85 grams in seedlings grown in oxygenated water. In case of seedlings grown in rockwool, the dry weights were 9.19 and 10.62 grams for the respective treatment. The differences between the dry weights were statistically significant at 0.05% level of probability.

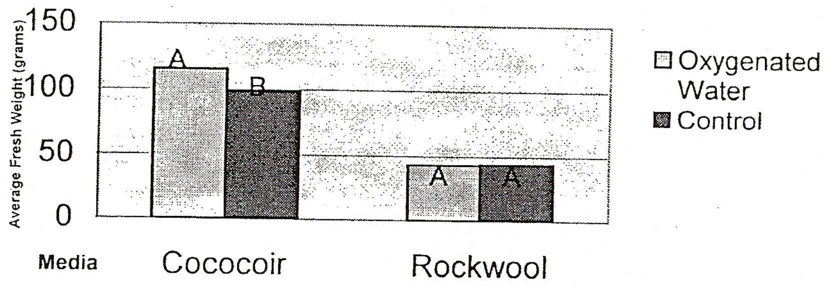
Effect of Oxygenated Water On the Dry Biomass of Cucumber Seedlings



Different letters in bars indicate significant differences at 0.05% level of probability

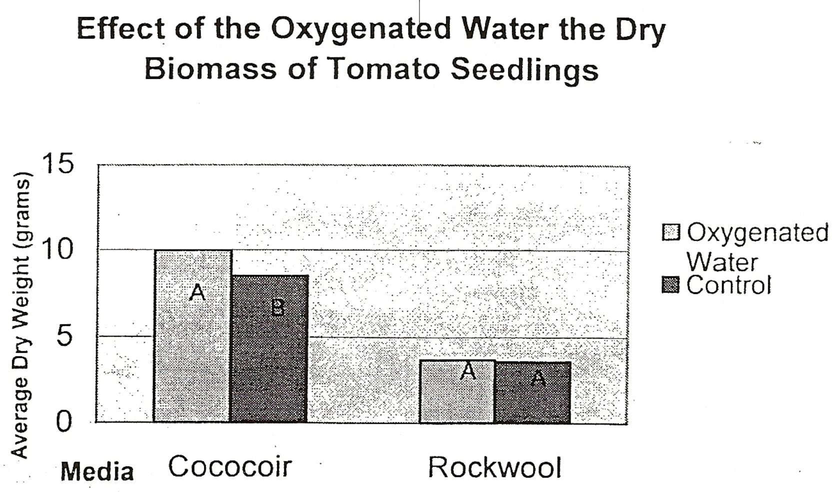
The following graph shows fresh weight of tomato seedlings grown in rockwool and coir with and without oxygenated water. The average weight of seedlings which were grown in coir using non-oxygenated water was 99.05 grams and it was 116.05 grams in seedlings where oxygenated water was used. The differences in fresh weight were statistically significant at 0.05% of probability. In case of seedlings grown in rockwool without oxygenated water the fresh weight was 8.51 grams as compared to 9.90 grams in case of seedlings grown in rockwool using oxygenated water.

Effect of Oxygenated Water on the Fresh Biomass of Tomato Seedlings



Different letters in bars indicate significant differences at 0.05% level of probability

The following graph indicates dry weights of seedlings grown in coir and rockwool. The weight differences between seedlings grown in coir were statistically significant while there were no significant difference in seedlings



Different letters in bars indicate significant differences at 0.05% level of probability

Discussion:

Results showed that cucumbers seedlings which were grown using oxygenated water had significantly ($p>0.05\%$) higher fresh and dry weights both in rock wool and coconut fiber when compared to plants grown in non-oxygenated water. In case of tomatoes the plants grown on COIR showed significantly higher fresh and dry weights when compared to those grown on regular water. The differences in fresh and dry weights were not significant in those tomato plants, which were grown on rockwool.

Cucumber seedlings showed a positive growth effect when they were grown on oxygenated water both when fresh and dry weights were compared and in both coir and rockwool. In case of tomatoes the differences were not significant between the treatments. It was observed that a large number of roots came out of the pot into the free standing water while in case of rockwool the tomato roots had a tendency to stat inside the block and oxygen availability may have been affected.

This study definitely showed a positive and significant growth affect in cucumber and tomato seedlings. Further studies are being planned in larger volume of growing medium and its affect on actual marketable yields of plants. With better root health, better plant growth and better yields may be expected.

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Future Research: SEAIR DIFFUSION SYSTEMS INC. is part of a funding consortium to study the affect of oxygenated water on the root health of cucumbers. The other partners in this study are Alberta Crop Industry Development Fund (ACIDF), Alberta Agriculture, Food and Rural Development, Alberta Greenhouse Growers Association, Red-Hat Coop and Pik-N-Pak Coop. This is a three years study in which role of oxygenated water in reducing root zone diseases will be examined.

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