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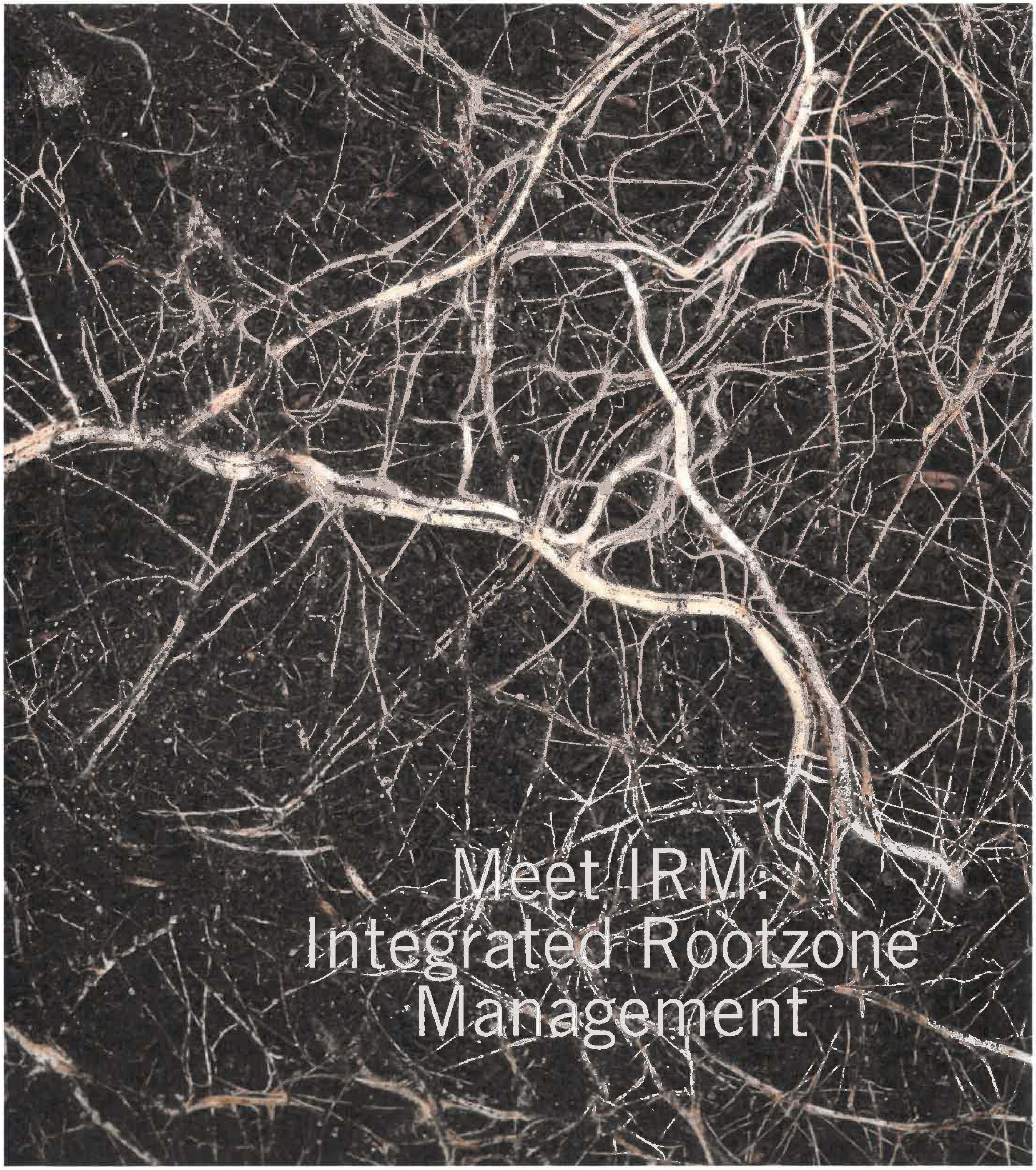

IMAGE CREDIT: Y. ZHENG

Integrated rootzone management: Is it key to production success?

BY
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I am sure you know of IPM, which stands for Integrated Pest Management, and you have likely been practising this in your operation for years with success. However, have you heard of IRM?

IRM stands for Integrated Rootzone Management which has a concept similar to IPM. IRM is a comprehensive approach to creating and maintaining a rootzone with adequate water, nutrients, and oxygen, within an appropriate temperature range, and without being limited by abiotic or biotic stressors. This can be achieved by considering the interrelated elements of the rootzone.

The rootzone is the environment where roots reside. When growing container crops in artificial growing substrates, from small plugs to large pots, substrate-filled troughs or bags, the rootzone is the environment within the containers. When growing in solution culture, the nutrient solution in contact with the roots can be considered the rootzone.

Solution culture and aeroponic systems have been successfully used on various crops for centuries. Clearly, plants can grow well without solid substrates as long as the roots are in an environment with adequate water, nutrients, oxygen, and temperature, and without biotic (e.g. pathogens) or abiotic (e.g. unwanted chemicals) limitations.

While it is not essential to have substrates for plant growth, soilless substrates (e.g. rockwool and mixes containing components such as peat and coir) are commonly used for plant production. For example, potted ornamentals need to be grown in pots with substrates for easy transport and display. Further, when vegetable crops such as tomatoes are grown in large greenhouse areas using substrates, horticultural management is easier and more forgiving (e.g. during a power outage). Substrates have buffering capacity against large disruptions such as water, temperature, pH and EC shifts in the rootzone. Conversely, when plants are grown in solution culture (e.g. nutrient film technique) or aeroponic systems, drought stress can be caused by a few hours without water delivery (e.g. during pump malfunction). When substrates are used, the dynamics of different environmental

Figure 1.
Photo A: Basil (*Ocimum basilicum*) performs better grown in a smaller pot (left) compared to those grown in larger pots (right), both in a peat and perlite mix. Photo B shows a close look of the typical waterlogging injury symptoms observed on plants grown in the larger pots from Photo A.

factors in the rootzone become more complicated than in solution culture and aeroponic systems. Environmental factors interact with each other such that a change in one factor can affect others. For example, adequate rootzone oxygen promotes strong, healthy plants that are resistant to pathogen infection; however, excessive substrate water content can reduce oxygen levels, creating an environment conducive to plant pathogens, which may, in turn, require the grower to increase pesticide use.

In soilless production, the most commonly controllable elements are: 1) growing substrate formulation, 2) oxygen and other gases, such as CO_2, through the choice of growing substrate, irrigation and other supplements (e.g. aeration of irrigation water, injection of certain chemicals such as hydrogen peroxide and aqueous ozone); 3) water status through irrigation; 4) nutrient composition and concentration through fertilization; 5) temperature through the control of atmospheric temperature, irrigation frequency, and irrigation water temperature; and 6) microbial community. All these elements are interconnected; therefore, to provide a healthy rootzone, an integrated approach is essential when dealing with them.

Let's take a closer look at key components of the rootzone, how they are interconnected, and the limitations caused by taking a non-integrated approach when dealing with these components.

GROWING SUBSTRATES

Growing substrates are used for providing physical support, retaining water and nutrients, providing air space for oxygen to diffuse into the rootzone and for harmful gases such as CO_2 and ethylene to move out freely. Common components of soilless growing substrates are peat, coir, wood fibre, bark, rockwool, perlite, vermiculite, sand, etc. Efforts have been made to find alternative materials for different regions and for different plant production systems. As agreed by many scientists, there is no one ideal growing substrate. However, in order to characterize and evaluate different substrates, researchers normally measure the following parameters: 1) physical properties, such as total porosity, container capacity, air porosity, and bulk density; 2) chemical properties, such as pH, EC, and the content, composition and availability of different nutrients; and 3) biological characteristics such as microbial community structure. The issue is that there are no internationally accepted standards or guidelines for assessing and reporting these parameters. Different plant species and cultivars, and even the same species at different developmental stages or sizes, require substrates with different characteristics. Further, if the same substrate is used, container sizes and shapes should be matched to the size of the plants. Figure 1 shows the performance of basil (*Ocimum basilicum*) plants when grown in the same substrate (peat and perlite mix) in either small or large containers. When basil seedlings were transplanted to a too-large container, the substrate in the container remained wet for too long, leading to oxygen deficiency and plant injury. Container size and shape can affect the substrate's physical properties as well, especially container capacity and temperature. Research with various substrates has also shown that different shapes of containers can affect plant performance.

Currently, methods for measuring both physical and chemical properties of substrates vary by region. For example, in measuring substrate physical properties such as container capacity and air porosity, many labs in North America use the NCSU porometer developed by Fonteno's lab at North Carolina State University, where the diameter and height of the sample cylinder are both 7.6 cm. In contrast, many European countries use the European Standard CEN TC 223 WG4 N151, which uses a double ring with a diameter of 10 cm and a height of 5 cm for each ring, and the measurement procedure is different as well. For a given substrate, different methods and devices can provide varying results for parameters such as water holding capacity and air porosity. Therefore, it is difficult to recommend a "perfect" growing substrate by simply specifying the physical properties without considering other related factors. A substrate can also work in one situation, but not for another, For example, different irrigation methods can have substantially different effects on plant performance in a given substrate. The "perfect substrate" simply does not exist.

When selecting a growing substrate, ensure that all the constituents are chemically and biologically stable, with no toxic compounds, and are pathogen-free. It is important that substrates are homogenous and consistent from batch to batch. This way, for a given substrate, plant and growing conditions, it is possible to develop effective horticultural management (e.g. irrigation) strategies to create a suitable rootzone environment.

OXYGEN AND OTHER GASES

Adequate rootzone oxygen is essential for healthy plants. Low rootzone oxygen is common in soilless production and can cause a variety of disorders in plants. Too much oxygen, which can be achieved by using modern water oxygenation technologies, can also harm plants and has been demonstrated by my previous research. When the rootzone is short on oxygen, plants are more prone to pathogens such as pythium root rot. Chérif et al. (1997) demonstrated that rockwool-grown tomato plants with low rootzone oxygen concentrations developed root rot symptoms earlier than those with higher rootzone oxygen concentrations. When inoculated with *Pythium* spp., tomato plants with high rootzone oxygen concentrations were less susceptible than plants with rootzone oxygen concentrations less than 5 mg/L. In a survey of commercial vegetable greenhouses in southwestern Ontario, we often observed crops with rootzone oxygen concentrations less than 2 mg/L. For this survey, rootzone oxygen concentration was measured using in situ oxygen sensors inserted directly into substrate bags of actively-fruiting plants.

Plant roots and microorganisms can produce other gases, such as CO_2 and ethylene, which may build up to harmful levels. When using growing substrates, it is essential that gas exchange between the rootzone and the atmosphere is unrestricted. Oxygen can diffuse over ten thousand times faster in the air than in water. This is why supplying dissolved oxygen (DO) in the irrigation solution may not be as effective as using a substrate with sufficient air porosity and good drainage. Our research demonstrated that even by using a nutrient solution with a DO of 20 mg/L to fertigate potted cut roses in coir substrate, there was no difference in rootzone oxygen levels compared to the control nutrient solution – both had DO levels of around 8.5 mg/L.

To ensure adequate rootzone oxygen levels, the selection of growing substrate, environmental (e.g. temperature) control and irrigation practices all need be considered holistically. When the growing environment is hot and humid, a substrate with high air porosity and better drainage is desirable for maintaining adequate rootzone DO. In such cases, more frequent irrigation can be used to manage rootzone oxygen levels and temperatures. High rootzone temperatures, which are normally associated with high levels of root respiration and microbial activity, can further reduce DO, raise harmful gas concentrations and can lead to proliferation of soil- and water-borne pathogens.

IRRIGATION/FERTIGATION

When an appropriate substrate is used, irrigation/fertigation management can be used to regulate most of the key rootzone environmental parameters. Aside from providing sufficient water and fertilizer, irrigation can bring in new dissolved and atmospheric oxygen, while helping to remove harmful gases and chemicals from the rootzone. If irrigation water is temperature-controlled, it can also be used to help adjust rootzone temperatures. This explains the old saying "the profit is in the hand of the person who holds the hose" in the greenhouse industry.

The question is when and how much to water? Irrigation frequency and volume are strongly correlated with rates of transpiration and evaporation, which are dependent on plant species, cultivar and size, container volume, the environment in which the plants are grown (e.g. light intensity, air temperature and humidity, etc.) and irrigation method (e.g. overhead, drip, sub-irrigation, etc.). Rather than using the conventional "lift, touch, and feel" methods of informing irrigation management decisions, many scientific studies have demonstrated that sensors (e.g. frequency domain reflectometry water content meters) can be successfully used to manage irrigation in soilless production. However, the microclimate even within modern greenhouses can vary drastically from one location to another. Our recent research has demonstrated that evaporation rate in one location of a modern greenhouse can be double that of other locations within the same greenhouse. These kinds of microclimate variations indicate that when the same substrate is used for the same crop in a greenhouse, either the substrate should have low water holding capacity for more frequent irrigation, or the irrigation frequency/amount should be varied by location within the greenhouse (which can be very difficult to manage, depending on the irrigation infrastructure).

It is also important to keep in mind that different substrates need different irrigation volumes and strategies. Researchers in North Carolina have shown that plants irrigated in the afternoon perform significantly better than plants irrigated in the morning, with 2 to 3°C reductions in rootzone temperatures when irrigated in the afternoon. Irrigation method can affect the rootzone environment in other ways. For example, our research shows that subirrigation can cause salts to accumulate to harmful levels near the upper surface of the growing substrate due to evaporation, whereas overhead irrigation can leach fertilizers from the growing media (also potentially leading to downstream environmental issues).

> The rootzone is a complicated system which demands an integrated approach...

NUTRIENTS

Fertilization is one of the most economical and most environmentally friendly tools in soilless crop production, where it can be used as either the "gas pedal" or the "brake". By applying the right fertilizer rate and formulation, one can have a crop ready for market weeks earlier, therefore reducing labour costs, improving space-use efficiency, saving water, and ultimately increasing profits.

Fertilizer requirements vary by substrate composition and growing conditions. During the summer months with high light levels, plants normally uptake and transpire more water. Therefore, feeding nutrient solution concentrations should be lower in the warmer months.

Fertilizer type and rate can also be used to manage the rootzone. For example, different nutrient compositions can affect rootzone environment and influence the availability of certain nutrients to plants and microorganisms. It is well-known that NH_4^+ uptake can decrease rootzone pH, while NO_3^- uptake can increase rootzone pH. Rootzone pH can also affect the availability of nutrients such as iron and phosphorus. Antagonistic and synergistic reactions exist amongst certain nutrients. For example, NH_4^+ competes with K^+ uptake, while NO_3^- helps the uptake of Ca^{2+} and K^+.

ROOTZONE MICROBIOLOGY

Rootzone microflora is comprised of both beneficial microorganisms and plant pathogens. Some irrigation strategies involve the capture and reuse of irrigation runoff and may spread pathogens throughout the greenhouse. It is common practice in North America to disinfect the runoff before reuse. However, most disinfecting technologies are largely ineffective if pathogens are already present in the rootzone, especially when the substrate is organic material (e.g. peat) based. It is also important to not harm beneficial microbial populations in the rootzone when using water disinfecting technologies that have 'residuals' – in other words, chemicals that persist beyond the point of contact, such as chlorine, ozone, copper, etc. Since most contemporary water disinfection technologies are ineffective at killing pre-existing substrate-borne pathogens, the inoculation of beneficial microorganisms into the rootzone is an alternative approach. Research has shown that some microorganisms can suppress plant pathogens in certain plant species when inoculated into the rootzone. A combination of fertigation solution disinfection and substrate inoculation with beneficial microorganisms has been suggested as a synergistic approach to managing pathogens in the rootzone. The effectiveness of beneficial microorganisms in suppressing pathogens can also be affected by other rootzone parameters, such as substrate water content, nutrients, pH and oxygen levels. Therefore, it is again important to take an IRM approach towards promoting beneficial microorganisms in the rootzone.

THE IRM APPROACH TO RESEARCH AND COMMERCIAL PRODUCTION

The rootzone is a complicated system which demands an integrated approach for effective management. Each component requires its own research. When it comes to crop production, all of the aforementioned components need to be taken into consideration simultaneously. When reading others' research, we need to keep in mind that "science is the intellectual and practical activity encompassing the *systematic* study of the structure and behaviour of the physical and natural world through observation and experiment" (Oxford Dictionary). Quite often, when researchers investigate whether a new material can replace contemporary growing substrate components (e.g. peat and coir), the same irrigation strategy is used for the control treatment. The suitability of the new substrate is evaluated based on whether its 'performance' is comparable to the control treatment, without considering the potential need to re-optimize the irrigation strategy (or any of a host of other parameters) to suit the new material. Conversely, when different horticultural management strategies (e.g. fertigation) are used in the aforementioned substrate trials, the researchers may be criticized for not using a 'true control'. In reality, due to time, space and funding limitations, it is generally not possible to take into account all elements of the rootzone environment in each trial. As long as we keep IRM in mind, and use *systematic* investigative approaches, the results should be scientifically acceptable and comprehensive. However, for this to succeed, it is essential for researchers to fully characterize their substrates and growing conditions, using acceptable methods for measurement and reporting, in order for the research results to be broadly applicable. For example, in a trial comparing different substrate materials, if irrigation can't be included as a variable, the researchers should at least clearly and precisely indicate how the plants were irrigated (e.g. at what substrate water status did irrigation start), rather than simply saying "irrigated as needed". Some recent studies have begun to consider the synergistic/antagonistic effects of interconnected parameters in the same trial.

In soilless plant production, an IRM approach requires growers to select the correct container (including size, shape and colour), substrate, fertigation strategies, etc., based on their plant species/cultivar, and climate and microclimate conditions. With so many different rootzone components and management strategies (e.g. irrigation/fertigation), how can a grower select the best combinations of these factors for their production system? Is it an optimized rootzone as long as there is adequate water, nutrients, oxygen and temperature, with no biotic or abiotic restrictions in the rootzone? If so, can we achieve this ideal scenario by measuring the mentioned rootzone parameters, then modifying them accordingly? More research is needed to address these questions. If it is acceptable, then in situ, real-time monitoring of rootzone environmental parameters would be ideal to help growers manage the rootzone. Currently, reliable and easy-to-use tools/sensor technologies are available for measuring some of these parameters, such as temperature, pH and water status (both water content and water potential); however, more research is needed to advance technology for in situ monitoring of other parameters such as nutrient composition and concentration, and oxygen levels.

IRM is a practical, powerful and cost-effective approach for successful soilless production. Growers and researchers should be mindful of the principles and practices of IRM, both in research and in production.

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