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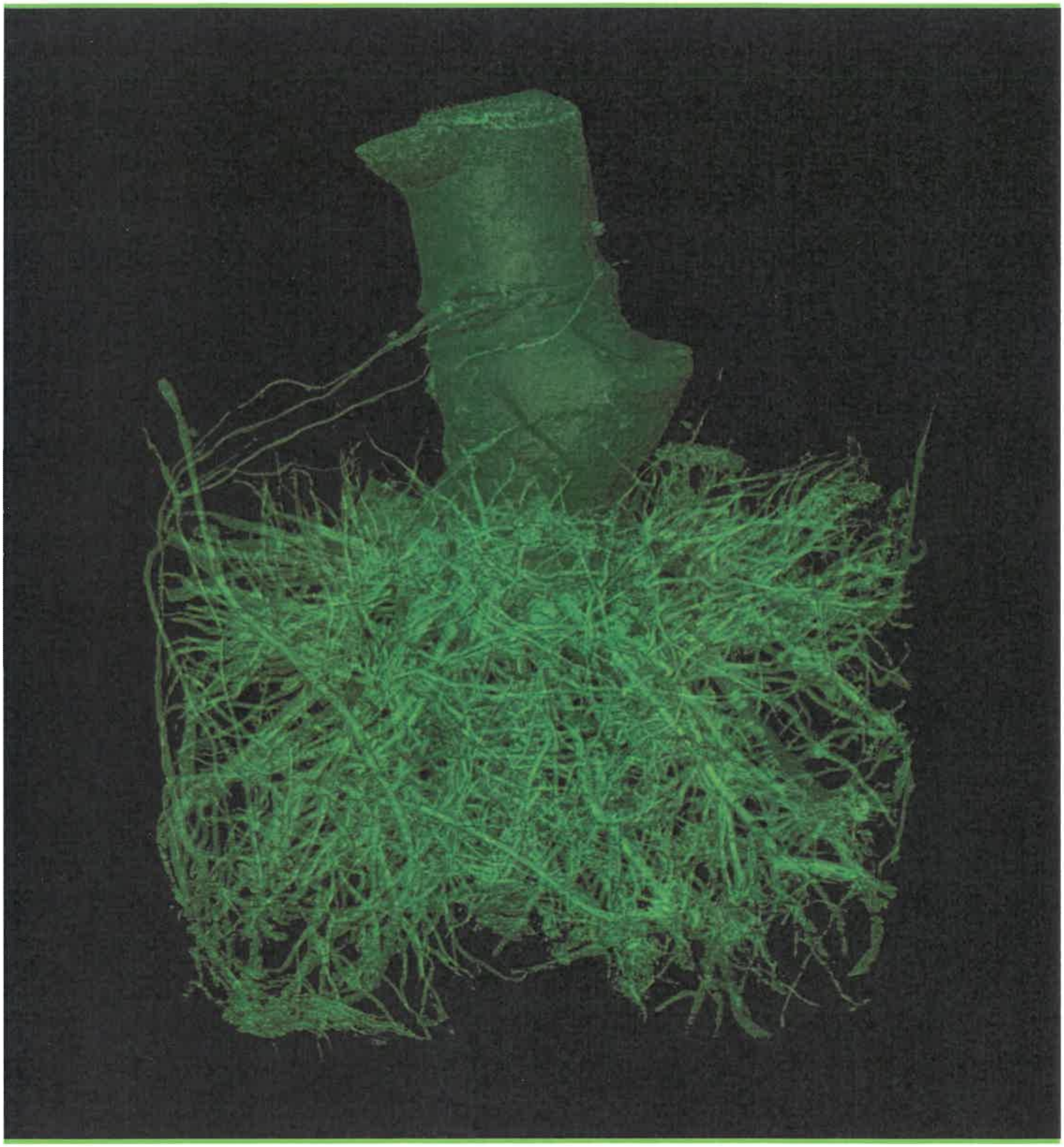

Novel soilless substrates

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Aging and handling studies of bark substrates provide better understanding on the use and management of these materials.

Novel soilless substrates

RESEARCH Soilless substrates are the way forward for growing many consumable horticultural crops, especially in areas of the world where arable land, water, labour, and poverty are critical challenges, suggests Dr Brian Jackson.

As precision agriculture and horticulture continue to evolve and as more and more food and other crops are being grown in soilless growing systems, the need for new, uniquely engineered, and highly specialised soilless substrates (growing media) will continue to increase. Manufacturers and researchers have steadily improved the composition, functionality, reliability, and consistency of the various substrates that growers around the globe rely so heavily upon to produce their crops.

Over the decades substrates have gone from being 'stuff in a pot' to being highly functioning and complex materials. Terms often used today by company sales reps, marketing promotions, researchers, and even growers to describe the manufacturing of soilless substrates include 'crafting', 'designing', 'formulating', 'constructing', 'engineering' among others. The science behind substrates is evolving and improving just like the genetics of the plants grown in them and the fertiliser, herbicides, growth regulators, etc applied to those plants. Many believe that substrates are to horticulture what Atlas is to the world he holds in the famous depiction from Greek Mythology… the foundation upon which all else is dependent.

Research on horticultural substrates has a long history around the world of providing critical answers to problems associated with growing plants in soilless culture. Many researchers have contributed to the improvement of growing practices to make horticulture production more efficient, enhanced, economical, and sustainable.

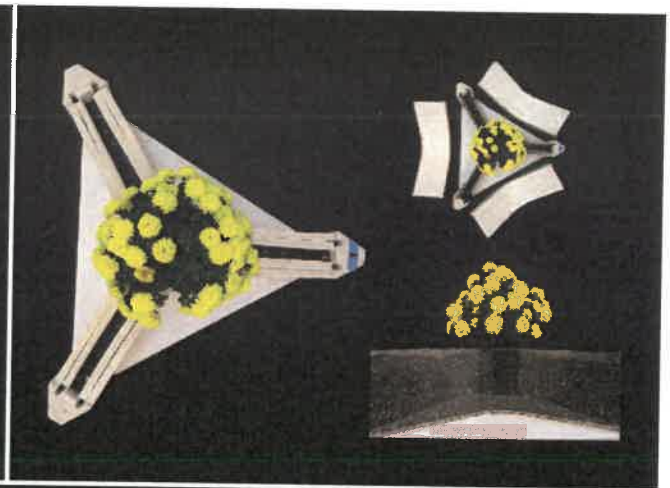
For over five decades scientists studying substrates have evolved and adapted their work around changing technologies, manufacturer and grower needs, environmental concerns, and governmental policies and regulations. Research first focused on finding suitable replacements for mineral soils in containers. Today, studies include a broader remit of creating and managing the proper root environment for more precise and controlled plant production. Many scientific, technological, and engineering advances in soilless substrates have been reported in the past decade.

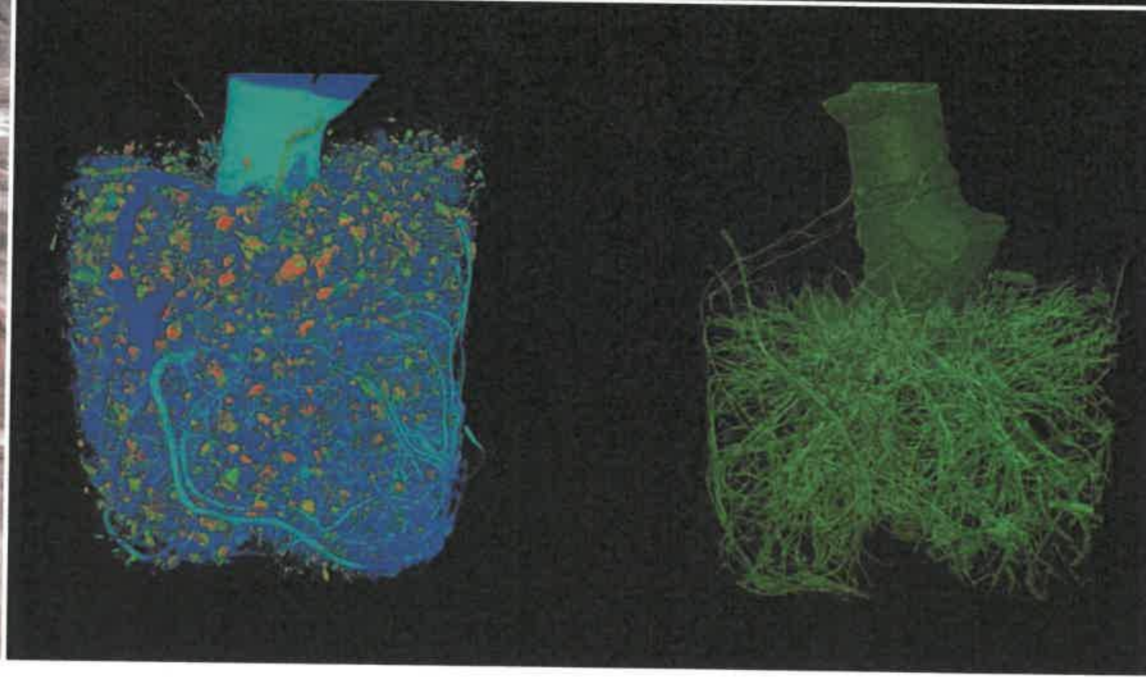
To emphasise the importance of soilless growing media, the volume of substrates consumed globally in 2020 was estimated to be 70-75 million cubic meters (m^3). These estimates are difficult to accurately project due to the lack of requirements or standardisation for reporting volumes and total sales of substrate materials by the manufacturers. Recent projections for global substrate demand have shed light on the challenges the industry faces in the years and decades ahead to meet the growing global demand for these materials. A recent study led by Chris Blok from Wageningen University (The Netherlands), projects the demand for substrates in 2050 to reach ~280 million m^3, a 240-250% increase in just the next 30 years.

Tomographic technologies

The first area of technological advancements to highlight is the use of image analysis to better and further understand the soilless environment and the plant roots growing in them. The opaqueness of containers and substrates has caused researchers to exercise some creativity to overcome their lack of visibility. When faced with the challenges of not being able to visualise what is happening in a container, we asked ourselves

Right: Tomographic scan of peat sample illustrating the solid particles and the spaces (pores) between them.
Far right: Mini-Horhizotron apparatus used for studying root growth of container-grown plants.
Below right: A rooted geranium cutting is rendered using a colour panel to differentiate substrate materials by their density (left) and the root system of the plant when isolated from the substrate (right).





the question, wouldn't it be nice to simply see inside?

If a doctor ever needed to see inside you, non-invasively, it's likely that a CT or Computer Assisted Tomography (CAT) scan would be used. Tomography, simply described, is the combination of hundreds or thousands of X-ray images, digitally reconstructed to render a 3D image. Since the first tomographic research studies in plant and soil relations were conducted in the mid- to late-1980s, it follows that the idea to subject plants and substrates to tomographic imaging is nothing novel. However, since the 80s, the capabilities of CT instruments and analytical software have improved by several orders of magnitude.

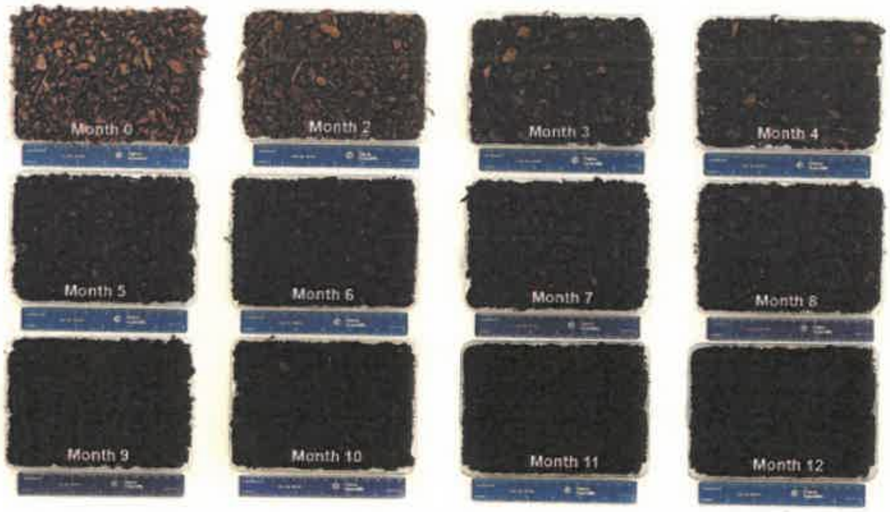
As examples of how the X-ray analysis is utilised in substrates, we tested (scanned) a series of materials to determine if, and if so, to what extent, we could see inside them to study their properties and environment. A scanned sample of peat moss shows the separation of solid particles and the spaces (pores) between them that can be filled with either water or air (porosity). It is typical for a peat substrate to have 80-85% porosity (therefore only 15-20% solid particles) and now for the first time we were able to 'see' this as it would be in a container. A later experiment analysed three peat samples that ranged in age and stage of decomposition. The youngest (blonde), middle-aged (brown) and the most degraded and oldest (black) peat samples showed clear differences in their particle size and structure, densities, and colour. Further analysis can yield more understanding of how these different peat materials affect various substrate and plant growth properties.

Aside from the physical and hydrological properties of the substrate, we were interested in the relationship that plant roots have with the substrate environment. There may be no greater dynamic relationship within a container than the relationship between plant roots and the substrate.

How do substrates affect root development? Conversely, how does root development affect the physical and hydraulic properties of the substrate? This 'non-invasive' attribute of tomographic research is particularly important when studying sensitive stages of plant growth and development such as root development of seedlings and vegetative cuttings. As an example, above shows X-ray scans of a geranium cutting in the substrate (left) and after software filters have removed the substrate exposing the inner root system (right). The scans are not only captured as photographs but, more importantly, as videos which bring to life the hidden world of a plant inside its container revealing the novelty of the technology.

Rhizometrics

Another large area of research has been the development of various techniques and methodologies for viewing, studying, and characterising the root growth of plants in containers called Rhizometrics. Among the different techniques developed is the Mini-Horhizotron designed to have three arms and six flat surfaces to observe and measure root growth while maintaining the water holding and drainage characteristics of a 16cm container. This flat-sided design increases the surface area to volume ratio 2.5 times over the 16cm round



Left: Pine bark aged for 0-12 months in a research project aimed at quantifying the changes in physical, chemical, and hydrological properties over time.
Below: Tomographic scans of blonde, brown, and black peat samples.

All photos: Brian Jackson

container. It includes shade panels to allow root development in the dark but can easily be removed to allow measurements. Comparisons with equivalent round containers showed no significant difference in root mass over a three-to-six-week period.

In previous studies the Mini-Horhizotron has been used to measure root length and development in many crop species. It has been used to determine the speed of root development over time, and the progression and severity of Pithium disease development non-destructively, as well as treatments that can reduce or suppress disease expression. It has also been used to observe the timing and location of root hair development. One of the best features of this rhizometric tool is that the device can be used for teaching and research purposes under normal greenhouse production conditions.

Substrate engineering

Advancements in organic material processing and engineering (specifically of bark and wood) have led to a better understanding of how various factors including moisture content, species, particle size, and machine type influence the consistency and reproducibility of these substrate components. New substrate fractioning and reconstruction techniques have been recently identified and studied to decrease weight/density and allow manufacturers to 'design and build' substrates for specific purposes.

Since their introduction to growers many years ago, the utilisation of wood substrate components has increased. The confidence that some growers and other industry partners have in the evolving world of wood in growing media comes after many years of public and private research trials and testimonials. To get to where we are today in our understanding of wood substrates, there have been some bumps along the way, including occurrences of poor/failed crop growth, issues with pH and nutrient tie-up, growth stunting due to toxicities, and irrigation management struggles, among others. Over time, research has found solutions to many of these issues and significant problems are not being reported as often by growers who have adapted their growing practices to better manage crops grown in substrates containing some percentage of wood.

While there is new interest in the use of wood-based substrate components, the importance and reliance on bark materials in substrates remains very high. More abundant in some countries than others, the use of processed bark components continues to increase. While both aged and fresh pine bark can be used successfully, little research has been done to investigate the differences between fresh and aged materials. Additionally, the actual age of pine bark used for research in the literature is usually not reported, making it hard to extrapolate anything more than general trends for bark that is considered 'aged.'

Over the decades there has been much speculation, but very little has been actually proven regarding the physical, chemical, hydrological, and biological effect that aging has on pine bark substrate materials. There are many variables that factor into the investigation of age on organic materials and how other inputs, additives, and biological entities interact and respond to these changing properties.

To gain a greater understanding of the effects of aging and pile management on pine bark substrates, a year-long (12 month) study was conducted at a commercial pine bark substrate site which included replicated windrows of specifically processed, screened, and monitored bark inventories. Over the course of this experiment, the effect of age on bark, which is common and expected could be easily seen. The thorough testing of the physicochemical properties allowed more detailed quantification and understanding of how the differing aged materials should be best managed when used in plant production.

Industry response

As global demand for substrates continues to increase, the manufacturers of these products are aware of their role in adopting advances in science and technology to help solve emerging issues that face growers and the horticulture industry as a whole. Initiatives are already being implemented on environmental preservation and stewardship, sustainability, carbon footprint calculations, life cycle analysis and cradle to grave/cradle assessments, substrate hygiene and safety measures, societal and socio-economic impacts and assessments, among others.

As part of a science-based approach to address problems and opportunities in the substrate industry, many manufacturers are employing new (some voluntary and some mandated) quality control measures and certifications to ensure sustainability efforts and environmental impact guidelines. Among the certifications and organisations that substrate companies participate in include the Organic Materials Review Institute (OMRI), The European Responsibly Produced Peat (RPP) certification program, and the Veriflora Scientific Certification System (SCS) Responsibly Managed Peatlands certification, among others.

Growing soillessly is the future of many consumable horticultural crops, especially in areas of the world where arable land, water, labour, and poverty are of critical challenges. Science continues to be innovative in offering solutions to current problems while also exploring opportunities for future production and grower challenges.

Soilless substrates will not only play a major role in maintaining quality of life for billions of people around the globe, but they will also be part of the answer to lessening poverty and hunger for billions more. There has never been a better time to be a researcher or user of soilless substrates.

Brian Jackson

Brian is Professor and Director of the Horticultural Substrates Laboratory at North Carolina State University, Raleigh NC, US. Brian has been active in soilless substrate research since 2003. He currently leads national and international research projects focusing on the engineering and utilisation of wood-based substrate materials. He frequently collaborates with fellow scientists and industry experts around the world to address the increasing demands, challenges, and opportunities faced by the growing media industry. Brian can be reached at brian_jackson@ncsu.edu