Combined Proceedings IPPS 68:349-355. 2018.

Substrates Trends for Propagation, Production and Profit

Brian E. Jackson and Paul C. Bartley
North Carolina State University, Department of Horticultural Science, 130 Kilgore Hall, Raleigh, North Carolina, 27695-7609, USA

brian_jackson@ncsu.edu

Keywords: Wood fiber, peat moss, fiber properties, coir; physical, chemical, hydrological, biological properties of wood; *Cannabis*, CAT scan, Computer Assisted Tomography, tomography.

THE REVOLUTION OF WOOD FIBER

Research on growing media (substrates) has been an important facet in the evolution of containerized horticultural crop production for over 50 years. During this time, we have relied on peat moss as the primary substrate component to grow most greenhouse crops. Peat moss is undoubtedly an ideal material based on its excellent physical and chemical properties. Research on substrates continues today as vigorously (maybe more) than ever, despite the successes and familiarity of our traditional peat-based mixes. Much has been reported in recent years about the development and potential of wood-based substrate components in the floriculture, nursery, and edible production industries here in the United States. These trends are equally, maybe more so emphasized, in many European countries and markets. Different regions of the world face different challenges related to horticultural system advancements, labor force issues, evolving consumer preferences and demands, as well as economic concerns and governmental policies and regulations.

Embedded in the discussions and product development in many European and North American companies is the continued interest in wood materials as components in indoor and outdoor crop production. As has been previously reported, there are now even more wood products that are being produced and used successfully (Figure 1). While visually different, these commercial materials have been and seemingly are, being used successfully. The scale to which many of these wood materials are being made has grown rather large over the years to the point that today, the color of peat and bark storage yards and production facilities is becoming more and more "blonde" in color (Figure 2)! The large-scale production of these materials is evidence of the increase in sales and demand for these products.

Figure 1. Wood substrate materials from European and North American manufacturers show variations in particle size and structure.

Figure 2. Success of many commercialized wood substrates has led to large-volume, mass production of materials for use in professional and retail products.

The majority of the wood products being commercialized are primarily made by one of three processes: 1) single or twin-screw extrusion; 2) twin disc refiners; or 3) hammer mills. The first two processes, used extensively throughout Europe, are thermo-mechanical techniques which involve high temperatures and friction to make the products. These technologies also exist here in the U.S. Wood products made with hammer mills are mostly confined to companies and grower operations here in the U.S., even though hammer mills are used for many purposes in the substrate industry throughout Europe for other material processing purposes. The differences among the different wood materials from these three processes include fiber size and thickness, sterility/chemical properties of the end-product, type of wood feedstock used, and varying abilities to be compressed, handled, and blended with other materials. Based on the resulting fiber properties and structure of wood produced from the different techniques, some may be better suited as loose-filled materials (blended with peat, bark, coir, etc.) while others are more capable of being compressed in small or large bales (Figure 3).

Compressed bales may offer unique advantages relative to storage and transport of these materials and are being used for both professional and retail/consumer soil and substrate products. Compared to “loose” fiber materials (not compressed) there is the added step of bale busting/loosening that must occur prior to substrate blending and use.

Figure 3. Some wood fiber materials can be easily compressed in different sized bales to aid in storage and transport.

There has been a tremendous amount of research conducted on wood substrates and substrate components over the past decade. The data and observations generated from those trials has been the foundation to all that we know today about the uses and potential of these substrate materials. While previous data is valid and has answered many questions (while generating many more), the learning curve for how to properly research, evaluate, and characterize these materials has been steep. As we understand more and more about the physical, chemical, hydrological, and biological properties of wood materials we have to continually evolve how we conduct our substrate research.

Based on all that we have learned in the past decade, when conducting trials today we must consider many variables (many of which are potentially confounding) about wood substrate materials before we conduct specific trials to learn more about a specific question. For example, we cannot design an experiment to understand fertility needs/issues (i.e. nitrogen immobilization) without considering and accounting for pH differences, liming adjustments, porosity variations, water/irrigation management, potential toxicities, etc. of the wood materials being tested compared to whatever control is being used. When these variables are known, considered and minimized as much as possible we get closer to comparing "apples to apples" as opposed to "apples to oranges" when comparing plant growth and substrate performance. Anytime data is presented (at trade shows, education sessions, company advertising, marketing propaganda, etc.) that shows plant growth differences or similarities as it relates to substrate performance or comparison to other products - it is important to keep in mind, and ideally ask the person presenting the data - what the conditions were that the crops were grown under (were all variables the same); and if the results were obtained from comparing "apples to apples" or "apples to oranges".

In addition to discussions about wood fiber and other "alternative" substrate materials for our current and future cropping systems, I would also like to applaud the peat industry for all that they are doing in support of continued substrate science and product development as well as their collective extreme awareness and involvement in sustainability and environmental stewardship. There continues to be debate and, in many instances, false narratives about peat and its sustainability in the future. A few things my travels and engagement with the peat industry both in North America and Europe have taught me is that they: 1) are committed to sustainability efforts; 2) are proactive with peatland management and restoration; 3) are adamant about maintaining proper harvesting techniques; 4) invest vast resources and efforts into product consistency and quality assurance; and 5) are willing to evolve as horticultural production needs and challenges arise in the future. Many peat companies are currently among the global leaders in wood fiber substrate development and commercialization - and they are excited to expand their product pallet to offer what growers want and need.

VISUALIZING SUBSTRATES

The opaqueness of containers and substrates have caused researchers to exercise some creativity to overcome their lack of visibility. To quantify total pore space and air space at container capacity, we saturate a substrate-filled container with water, weight it, allow it to drain, and weight it again. To get an idea of the pore structure and how water may move through the system, we incrementally apply pressure to the container and associate the volume of water drained and pressure applied as a function of pore diameter. If root growth data is being looked at, the most common way to do so is by painstakingly handwashing rootballs to carefully separate the roots from the substrate. Instead of going through all of these time consuming and invasive procedures, would it not be nice to simply - *see inside*?

If a doctor ever needed to non-invasively *see inside* you, it's likely that you have had the misfortune of experiencing a CT or CAT scan (Computer Assisted Tomography). Tomography, simply described, is the combination of hundreds or thousands of X-ray images which are reconstructed to digitally render a 3D object. This donut-shaped, claustrophobia-inducing instrument once exclusively utilized in the medical and petroleum industries is finding new uses (and maybe more willing patients) in other research fields. Since the first tomographic research studies in plant and soil relations were conducted in the mid- to late-1980's, it follows that the idea to subject plants and substrates to tomographic imaging is nothing novel. However, since the 1980's, the capabilities of CT instruments and analytical software have improved by several orders of magnitude. Images can be captured at the micrometer and nanometer scale - compared to the millimeter scale. Access to a CT instrument no longer requires a doctor's appointment. In collaboration with the Shared Materials and Instruments Facility at Duke University, we in the Horticultural Substrates Lab at North Carolina State University are finally capable of seeing our substrates and plants *inside and out* in both 2D and 3D.

In preliminary scans, substrate components were packed into 7.6 cm (3-in.) cores and scanned at a resolution of 50 microns. Qualitative differences in the inherent physical structures of each material were apparent (Figure 4).

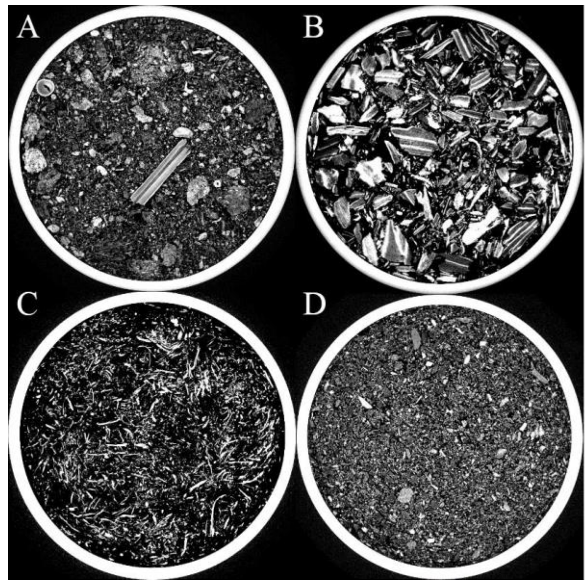

Figure 4. Two-dimensional horizontal slices of peat (A), pine bark (B), wood fiber (C), and coconut coir (D) substrate components packed in 7.6 cm (3-in.) diameter polyacrylic cores.

Peat may be best described as a heterogeneous mixture of fibrous particles and partially decomposed stems. Coir, thought to be very similar in texture to peat, appeared more homogenous and consisted of granular shaped, sponge-like particles. Pine bark appeared the coarsest and contains particles consisting of two layers, the dense periderm layers (brighter white layers) and less dense layers comprised of crushed phloem and expanded parenchyma cells (grey layers). The elongated, fibrous network of wood fiber substrates visually distinguished it from other materials.

To examine the effect of water on CT scans, two pine bark-filled cores were analyzed, one irrigated and another not irrigated. Since the density of water and organic components are similar, it can be difficult to discern what is water and what is pine bark in the irrigated sample. However, what is apparent is the spatial distribution of water in the container. From this orientation, the layer of water held by capillary tension in the irrigated sample, commonly called the "zone of saturation," stands out in bright contrast from the non-irrigated sample (located between 0 and 20 mm; Figure 5).

Figure 5. Pine bark cores were analyzed before and after irrigation. White or light grey objects indicate the presence of solids and water. Black spaces indicate air-filled regions.

A valuable relationship to understand is that between substrates and roots. However, separating plant roots and substrates from CT scans can be challenging as both components are organic and comprised of similar elements. In order to isolate a root system, there must be sufficient contrast created between the roots and substrate. Under the appropriate conditions, this contrast can be created and reveal remarkable detail in the plant's root architecture (Figure 6). Similar to substrate characterization, 3D rendered root systems can be characterized by root volume, length, surface area, and diameter.

The spatial distribution of the root system can also be characterized with the same analyses used to generate data for water distributions within a container. 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 substrate physical and hydraulic properties? Aside from substrate/root affects, this technology may allow any abiotic and biotic growth affects, particularly during sensitive stages of plant development, to be non-invasively studied.

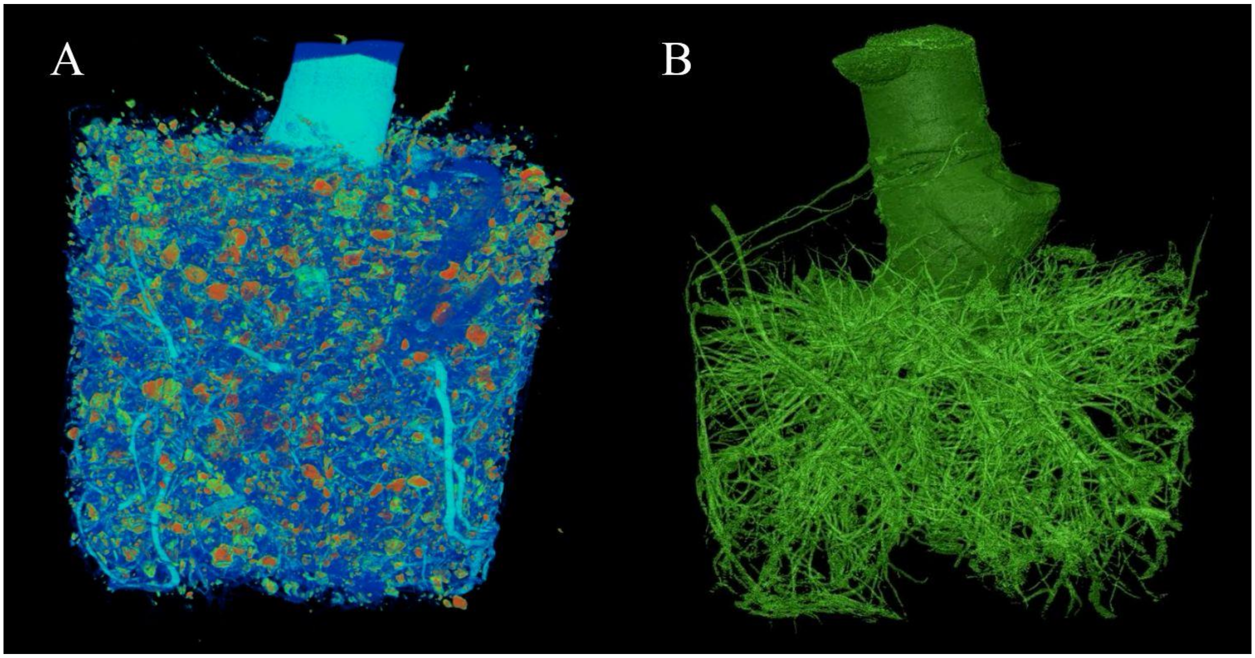

Figure 6. (a) A root geranium cutting is rendered and displayed using a color panel to differentiate materials by their apparent density. (b) Given sufficient contrast, the root system of the plant can be isolated from the substrate and analyzed.

The factors affecting callus tissue development after cutting propagation or grafting could be observed without laying a finger to the plant. The extensive research being conducted to understand the genetic traits responsible for specific root characteristics could be accomplished *in situ*, offering a unique perspective with 3D characterization. There is no doubting the significance future tomographic research could have in the area of plant growth and development.

THE FUTURE IS/OF CANNABIS?!

Is *Cannabis* a horticultural crop? If it is grown indoors under controlled environment conditions, it most certainly is! If grown outdoors (much of the industrial hemp industry) on a large acreage basis - then it may fall more under agronomic jurisdiction depending on who you ask. Regardless the designation, *Cannabis* that is grown in containers requires the use of some substrate (growing media, medium, soilless media, potting soil, etc.) for production. The cannabis industry, due to legal hurdles and crippling stigmas, is somewhat deprived of scientific literature on many production practices and issues. Growers and industry professionals rely heavily on personal experience and information from other industries (i.e. Floriculture/Greenhouse). When personal experience is not enough, they are often forced to online forums, YouTube videos, and decades old handbooks for information. Although hands on experience is an invaluable source of knowledge, having a scientific base of information to rely on can greatly expedite the learning process for growers, both experienced and inexperienced. A specific area in need of information is that of container substrates.

At NC State University, the Horticultural Substrates Laboratory began in the mid 1980's and has since become one of the only laboratories in the world that solely focuses on substrate science to assist growers and retailers/consumers with substrate-related issues and opportunities. Currently, Drs. Brian Jackson (Director) and Bill Fonteno (Founder) operate this lab with responsibilities in conducting grower and industry trials, substrate diagnostic testing, soil/substrate certification, graduate student training, and course instruction.

In 2018, we have received permits to grow/research *Cannabis* (low THC/high CBD) and now are broadening our research pallet to include the needs and opportunities of the ever-growing *Cannabis* industry (Figures 7 and 8).

Figure 7. *Cannabis* trials (CBD Oil Industrial Hemp) at NC State University are beginning to yield some of the first scientific data on substrate-water-plant interactions in controlled environment production.

Current and future understanding of *Cannabis*-substrate interactions will increase drastically as more and more state institutions (and private) are allowed to research and study these crops. Grower trials and experimentation will also continue to provide reliable information about containerized *Cannabis* production. Growers can conduct accurate and reproducible trials at their operations. Research does not have to be conducted in a laboratory! The perfect balance of science and application exists in grower and researcher partnerships which has been the key to success for numerous other horticultural industries.

Figure 8. Indoor production of container-grown *Cannabis* relies on many different organic and inorganic growing media (substrate) components.