agriculture

MDPI

Article

Surveying North American Specialty Crop Growers' Current Use of Soilless Substrates and Future Research and Education Needs

Jeb S. Fields [1,*], James S. Owen, Jr. [2], Alexa Lamm [3], James Altland [2], Brian Jackson [4], Lorence Oki [5], Jayesh B. Samtani [6], Youbin Zheng [7] and Kristopher S. Criscione [1]

1. Hammond Research Station, Louisiana State University Agricultural Center, 21549 Old Covington Hwy., Hammond, LA 70403, USA; kcrisc2@lsu.edu
2. Application Technology Research Unit, 1680 Madison Ave., Wooster, OH 44691, USA; jim.owen@usda.gov (J.S.O.J.); james.altland@usda.gov (J.A.)
3. Department of Agricultural Leadership, Education and Communication, University of Georgia, 132 Four Towers, Athens, GA 30602, USA; alamm@uga.edu
4. Department of Horticultural Science, North Carolina State University, Raleigh, NC 27695, USA; brian_jackson@ncsu.edu
5. Department of Plant Sciences, University of California, MS6 One Shields Ave., Davis, CA 95616, USA; lroki@ucdavis.edu
6. Hampton Roads Agricultural Research and Extension Center, School of Plant and Environmental Sciences, 1444 Diamond Springs Rd., Virginia Beach, VA 23455, USA; jsamtani@vt.edu
7. School of Environmental Sciences, University of Guelph, 50 Stone Rd. E., Guelph, ON N1G 1M3, Canada; yzheng@uoguelph.ca

* Correspondence: jfields@agcenter.lsu.edu

Abstract: Many specialty crop growers are transitioning high-value crops from in-ground production to soilless culture due to the diminishing availability of fumigants, increasing pest pressure, extreme weather, and the need for flexible production practices. The objective of this study was to determine the research and educational needs of specialty crop growers who are transitioning to soilless substrates. North American growers were surveyed using an online instrument that incorporated Likert-type statement matrices, open-ended questions, and demographic questions. Additionally, two virtually led focus groups were conducted to further expand upon the quantitative findings with descriptive data. Respondents indicated the most important factors in considering whether to adopt soilless substrates were improving, managing, and reducing overall plant quality, disease management, and crop loss, respectively. The most important research needs were understanding the effects of substrates on crop quality and uniformity, fertilizer management, and economic costs and benefits/return on investment. In both the grower survey and focus groups, crop quality and uniformity were among the highest-scored responses. Food safety, disease and pest management, consumer perception, substrate disposal-related issues, transportation, and return-on-investment were also identified as important factors when considering soilless substrates.

Keywords: growing med; stakeholder; greenhouse; nursery; vegetable; small fruit; controlled environment agriculture; irrigation; fertility; disease

Citation: Fields, J.S.; Owen, J.S., Jr.; Lamm, A.; Altland, J.; Jackson, B.; Oki, L.; Samtani, J.B.; Zheng, Y.; Criscione, K.S. Surveying North American Specialty Crop Growers' Current Use of Soilless Substrates and Future Research and Education Needs. *Agriculture* **2023**, *13*, 1727. https://doi.org/10.3390/agriculture13091727

Academic Editor: Aocheng Cao

Received: 2 May 2023
Revised: 28 August 2023
Accepted: 29 August 2023
Published: 31 August 2023

1. Introduction

Production of specialty crops in containers is essential in North America and beyond as a way to provide food (i.e., fruits and vegetables) [1], improve human wellness (i.e., ornamentals and therapeutic gardens) [2], and support functional ecosystem services (i.e., ecological restoration) [3]. Specialty crop producers that traditionally produce crops in the ground are shifting to production in containers using soilless culture systems. This is primarily due to (1) the diminishing availability of resources (e.g., arable land and fresh water), (2) the reduction in available pesticides (e.g., fumigants) and subsequent increases in pest pressure, (3) increasing efforts to minimize distances to marketplaces, (4) offsetting food deserts (i.e., urbanization), (5) the need for flexibility in an evolving global marketplace (i.e., genetically modified crops and advances in production management methods), (6) global pandemics driving the demand for more specialty crops (i.e., COVID-19) [1], and (7) extreme weather caused by global climate change. In view of these shifts, there has been an increase in all U.S. specialty crop sales of 18% over the last decade (2009–2019) [4], and soilless substrate use is predicted to increase by >400% world-wide [5]. Soilless culture provides an interchangeable system for production of ornamentals, vegetables, small fruit, tree fruit and nuts, and other emerging crops [6,7]. This is especially true where the soil is unsuitable for the desired crop and water is limited [8]. Soilless culture systems are more space- and resource-efficient (i.e., water and nutrients) [9] and can increase yield due to more crops per area and year-round production [1] when compared to in-ground farming. Plus, production of crops in soilless culture is often the only option in urban areas where soils are contaminated with heavy metals and other pollutants (Pennisi et al., 2016). This is important considering the percentage of megacities (i.e., cities with >10 million residents) is projected to increase by 10% by 2030 [10].

Growers transitioning to soilless culture will require multifunctional substrates that are engineered to optimize growth and yield and are resource efficient to reduce water waste, effectively retain mineral nutrients, and alleviate agrochemical loss. This must be accomplished while simultaneously remaining regionally available and economically sustainable. The primary role of a soilless substrate is to serve the demands imposed by containerized roots [9]. Thus, for optimal plant growth and health, an ideal soilless substrate should enable growers to easily utilize horticultural management strategies to provide the plant rootzone with an adequate and balanced amount of water, oxygen, mineral nutrients, and a stable temperature, ultimately reducing abiotic or biotic stresses. In addition, long-term crops, such as small fruit, are sometimes grown ≥10 years. In view of this, these cropping systems require substrates that are chemically, physically, and biologically stable long enough to function optimally, posing an entirely new set of challenges for soilless substrate science. This will likely involve reimagining all phases of production and the implementation of soilless culture.

Existing and new issues will continually need to be addressed as current specialty crop sectors evolve and new sectors begin to transition to soilless substrates. The needs of stakeholders transitioning crops to container production are likely different than those of current users with regards to management systems [1,9]. Thus, strategic needs will continue to include efficient substrates with optimized physical, hydraulic, and chemical properties, with new target areas such as substrate biology, long-term substrate management, acquisition logistics, transportation, and alternative materials. The authors hypothesize that growers will be interested in transitioning to soilless culture but will require additional support and education to ensure a productive transition. This research was designed to identify opportunities and challenges to inform the research and educational needs necessary to support specialty crop growers in North America who utilize or will potentially implement soilless production in conventional (e.g., greenhouse) or emerging (e.g., vertical farming) cropping systems.

2. Materials and Methods

A mixed-method research design was used to better understand the research and education needs of North American specialty crop growers who have already adopted or plan to adopt soilless substrates. An online survey was used to collect quantitative data, followed up by a focus group to obtain an in-depth understanding of the issues with qualitative data [11].

2.1. North American Specialty Crop Grower Survey

North American specialty crop growers were surveyed from September through November 2020 using an online instrument developed by [12] that was adapted to fit the context of this study. Purposive sampling was used to identify potential respondents through regional associations, industry periodicals, and extension contacts in North America. After three months of data collection, 180 responses were obtained and deemed representative based on their geographic location, size of operation, and type of plants grown.

The survey instrument included 23 separate questions that incorporated Likert-type statement matrices, open-ended questions, and demographic questions. A definition for soilless substrates was provided at the beginning of the survey to ensure clarity of response: "*The term soilless substrate used within this survey is synonymous with growing media, potting mix, or components of solids used in hydroponics*". Respondents were initially asked to indicate the physical location of their production facilities by selecting 'all that apply' from a list of options including: Western U.S.; Midwestern U.S.; Southern U.S.; Northeastern U.S.; Mexico and Central America; Central Canada and the Atlantic Region; Western Canada (Pacific Region) including British Columbia; and Canadian Prairie Provinces. Respondents were also asked to indicate what type of crop they produce using a categorical check 'all that apply' question with the options: vegetables; small fruit; tree fruit and nut; ornamentals; hemp/cannabis; and other. Respondents were then asked to indicate the type of crop product they produce from a check 'all that apply' list: liner or transplant; finished product; other; or none of the above. Finally, respondents were asked to indicate the annual sales value of their crops grown in 2019.

Two questions were used to identify respondents' current use of soilless substrates. The first question asked respondents to indicate if they currently used soilless substrates in their plant production operation. If respondents indicated they did, they were asked the percentage of their crops grown using soilless substrates in 2019. If the respondent indicated they did not use soilless substrates, they were asked if they were interested in using soilless substrates in the future. If they indicated they were interested, they were asked what percentage of their crops they believed they would grow on soilless substrates over the next five years. If they indicated they were not interested, they were asked why they were not interested in adopting soilless substrates.

A single open-ended question was asked of those who indicated they currently use or are interested in using soilless substrates to determine what plants were being grown in soilless substrates. The respondents were simply asked to list the species they were currently growing or were most interested in growing using soilless substrates.

Respondents were then asked to indicate how important 16 factors were in their decision to adopt or not adopt soilless substrates. The 16 factors included: economic costs and benefits; increase crop uniformity; improve labor efficiency; increase your ability to produce more in the same land area; disease management (e.g., pathogens or nematodes); improve overall plant quality; faster germination or rooting; faster to market; reduce shrinkage (e.g., reduce crop losses, increase survival during rooting); increase duration of growing season; water management; reduced pesticide use; existing soil quality; local availability of soilless substrate materials; ability to qualify for specific programs (e.g., organic, sustainable); and other. The level of importance was indicated by responses on a five-point Likert-type scale (1 = not important at all; 2 = slightly important; 3 = moderately important; 4 = very important; 5 = extremely important).

To determine the soilless substrate research and education needs, respondents were asked to indicate how important 12 topics were in helping them with their adoption or success using soilless substrates. The 12 topics included: clear options, plans, and guidelines for use; selecting materials to use with specific crops; training materials for staff; economic costs and benefits/return on investment; automation and mechanization (from production to harvest); chemical application methods (pesticides, micronutrients, PGRs); disease and pest management; effects on crop quality and uniformity; effect on production time (weeks, months, years); fertilizer management; water management; and labor management. The level of importance was indicated by responses on the five-point Likert-type scale previously mentioned.

A panel of researchers specializing in social science research, survey design, agricultural economics, and horticulture reviewed the instrument for content to ensure it was adapted appropriately to answer the survey questions [13]. The instrument was also reviewed for construct validity to ensure the survey questions were appropriate for the audience and relevant to answering the survey questions [13]. The study was deemed exempt by the University of Georgia Institutional Review Board. Data were analyzed descriptively using frequencies, percentages, and means as measures of central tendency using statistics software (SPSS 27, a Chicago, IL, USA).

2.2. North American Specialty Crop Growers Focus Groups

Once the survey data were collected, two virtually led focus groups (one with growers from the western half of the North American continent and one with growers from the eastern half of the North American continent) were conducted to further elucidate the quantitative findings with descriptive data. A moderator guide was developed and used for both focus groups to ensure consistency. The guide was reviewed by a team of social science and horticulture researchers to ensure its validity.

Travel was restricted at the time of the study due to the COVID-19 pandemic; therefore, participants engaged in the focus groups via an online communication platform (Zoom, San Jose, CA, USA) that allows participants to see one another at once, raise their hands both physically on camera and technologically using the program, and chat in a separate side space with the entire group or with one another. Given that new technology was being utilized, participants were briefed on how to participate in a detailed email sent out prior to the session to reduce the limitations of not being present in the same room together. In addition, detailed instructions were provided by the moderator at the beginning of the session on how to ensure their screen showcased the videos of all participants, how to mute/unmute, how to use the chat box, and how to turn their cameras on/off.

A team of horticulture researchers with specializations in soilless substrate research purposefully selected 12 focus group participants to ensure all aspects of the specialty crop industry were represented, including those that have and have not adopted soilless substrates [14]. In addition, an effort was made to ensure representatives of both large (>$1,000,000 in annual sales) and small (<$1,000,000 in annual sales) operations were present in the conversations. Four individuals participated in the focus group for the west and eight in the focus group for the east.

A moderator and an assistant moderator, who had not previously worked with any of the participants, conducted the focus groups to reduce bias. After debriefing on the Zoom technology's use, participants were assured of their confidentiality. Input from the moderator was minimal, and conversation flowed naturally between participants. The moderator did ask for input from individuals who were not contributing at times throughout the session.

The focus group was audio recorded, and the assistant moderator took notes that were used for member checking and later for triangulation in the data analysis process [15]. For member checking, the notes were summarized by the assistant moderator at the conclusion of the session, and participants were asked to reflect upon their accuracy [15]. Both sets of audio recordings were transcribed verbatim, and pseudonyms were assigned to participants to ensure confidentiality. The data were analyzed using MAXQDA (http://www.maxqda.com), a qualitative coding software (Berlin, Germany), using basic content analysis [16]. Since there was a small and easily identifiable group of potential growers that could participate in the session, the demographics of the participants were not included to ensure confidentiality of the responses. Themes, patterns, and relationships of thought were identified by a coder who was not involved in conducting the focus groups to ensure objectivity. The results were discussed and peer debriefed by a team of four additional researchers to ensure the transferability of the results [15].

Data Integration. Survey data and focus group data were analyzed independently and then integrated for results interpretation [16,17]. Typical of a mixed-methods study, the qualitative results were used to corroborate and further inform the quantitative results [18].

3. Results and Discussion

3.1. Grower Survey

Survey respondents represented production facilities in the Southern U.S. (39.3%), Midwestern U.S. (18.7%), Western U.S. (15.6%), Northeastern U.S. (10.9%), Central Canada and the Atlantic Region (9.0%), Western Canada including British Columbia (3.4%), Mexico and Central America (3.1%), and the Canadian Prairie Provinces (1.6%). Nearly half (49.2%) of the respondents identified as Caucasian. There were 145 male respondents and 35 female respondents, who ranged in age from 25 to 87. Most respondents had at least a 2-year college degree (83.5%). Small farms (with <$100,000 in annual sales) represented over half of the survey respondents (54.3%), with 21.4% of respondents averaging between $100,000 and $1,000,000 in annual sales. The remaining 24.2% reported >$1,000,000 in annual sales. These values are likely to shift in the future. The U.S. Census of Horticulture [4] showed that in the last two decades, though there have been fewer horticultural operations, annual horticultural sales have increased by nearly 25%.

There was a relatively uniform distribution of specialty crop sectors represented by survey respondents (Figure 1). The most common were vegetables (34.3%), followed closely by small fruit (32.7%) and ornamentals (32.1%; Figure 1). The 19.0% indicating they produced "other" crops mentioned growing: flowers, Christmas trees, native plants, herbs, and mushrooms. It is possible for these proportions to also shift in the future since the increase in urbanization within megacities will undoubtedly influence horticultural operations. The increase in global population will drive food demand for high-quality and nutritious crops upward and surge production of these crops to sustain the growing population. Moreover, considering the number of megacities is increasing, more food will need to be produced locally (i.e., near cities or within cities via vertical/rooftop gardening) [1] to combat food deserts. Plus, with higher standards of living, greater average household income, and urban inhabitants desire to live in aesthetically appealing environments (i.e., balcony/terrace container plants, house plants, street and park landscapes, etc.), ornamental crop production (and soilless substrate use) will be driven to expand further [5]. With consideration that soilless production continues to be an effective tool for sustainably cultivating many specialty crops, the proportion of growers that grow "other" specialty crops (19%) may increase due to the rapid transition and interest in soilless systems [1].

Over half of the respondents reported producing finished products (62.0%), while 26.5% reported producing liners or transplants. Liner and transplant production may increase in the future as well since there is an increasing demand for ecological and pollinator habitat restoration work [3,19]. Under 10% of respondents indicated producing cannabis for industrial purposes (hemp fibers) or medicinal purposes (cannabinoids); however, many expressed interest in future opportunities with those crops. Cannabis production in soilless culture is growing rapidly [1,20] due to the tightly controlled growing conditions [21] and alone has a tremendous economic impact in North America (>$35 billion in Canada and the U.S. combined) [21,22]. Others indicated a variety of species, often stating they grew over 75 species. These global and national trends justify assessing the current North American soilless substrate usage to better prepare for the upsurge in specialty crop production.

Most growers surveyed (73.5%) reported they currently utilize soilless substrates for crop production, with 66.5% of those respondents producing over 75% of their crops with soilless substrates (Figure 2). Almost half of respondents (47.8%) not using soilless substrates indicated that they were interested in adoption. Adopting soilless substrate management practices will likely include changes in other management system shifts in land utilization (i.e., container spacing, greenhouse structures, plot arrangements, and orientations), fertilizer application rates, type, and delivery style, equipment (i.e., substrate mixers, hopper systems, greenhouse components) [9], and energy costs (i.e., irrigation pump, greenhouse electricity, etc.). Refs. [1,23] stated that one of the greatest barriers for growers changing their soilless substrates is compatibility with their current irrigation systems, especially since differently sized containers are more resource efficient under different irrigation delivery systems [24]. Respondents who were uninterested indicated numerous reasons, including lack of interest, associated costs, not being an organic farming practice and being perceived as unnatural (the USDA allows hydroponic culture to be certified organic), and not being practical for their product.

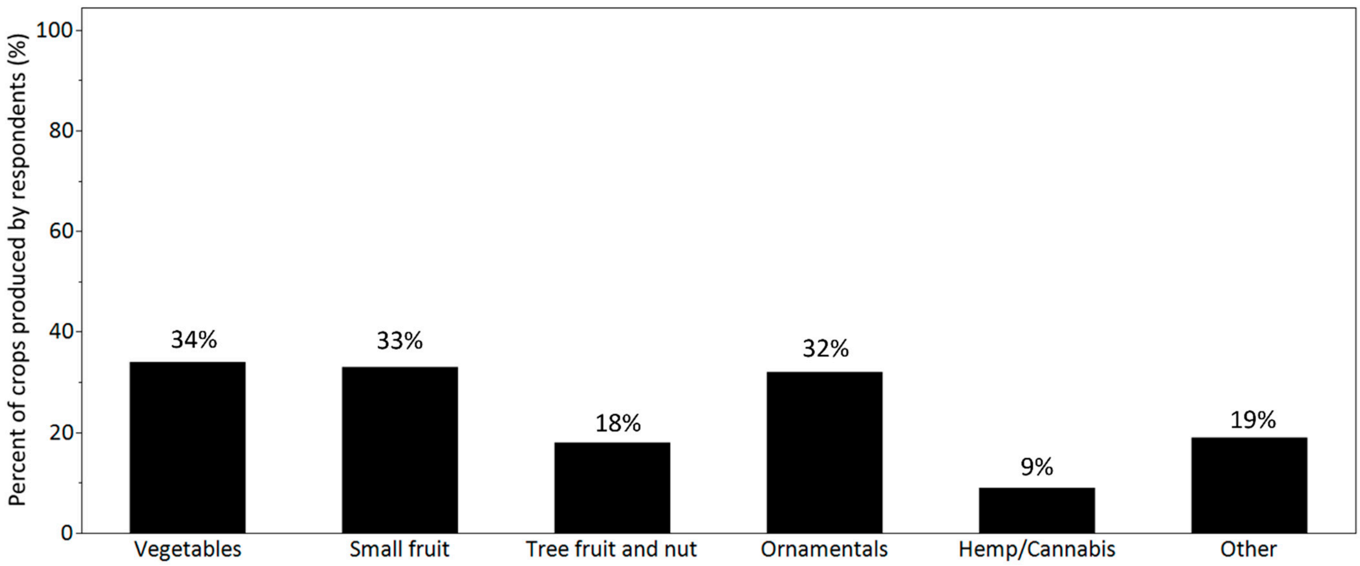

Figure 1. Distribution of 180 North American specialty crop producers responding to a survey on current and future use of soilless substrates. Some respondents grew more than one category of crop commodity, thus contributing to multiple sectors.

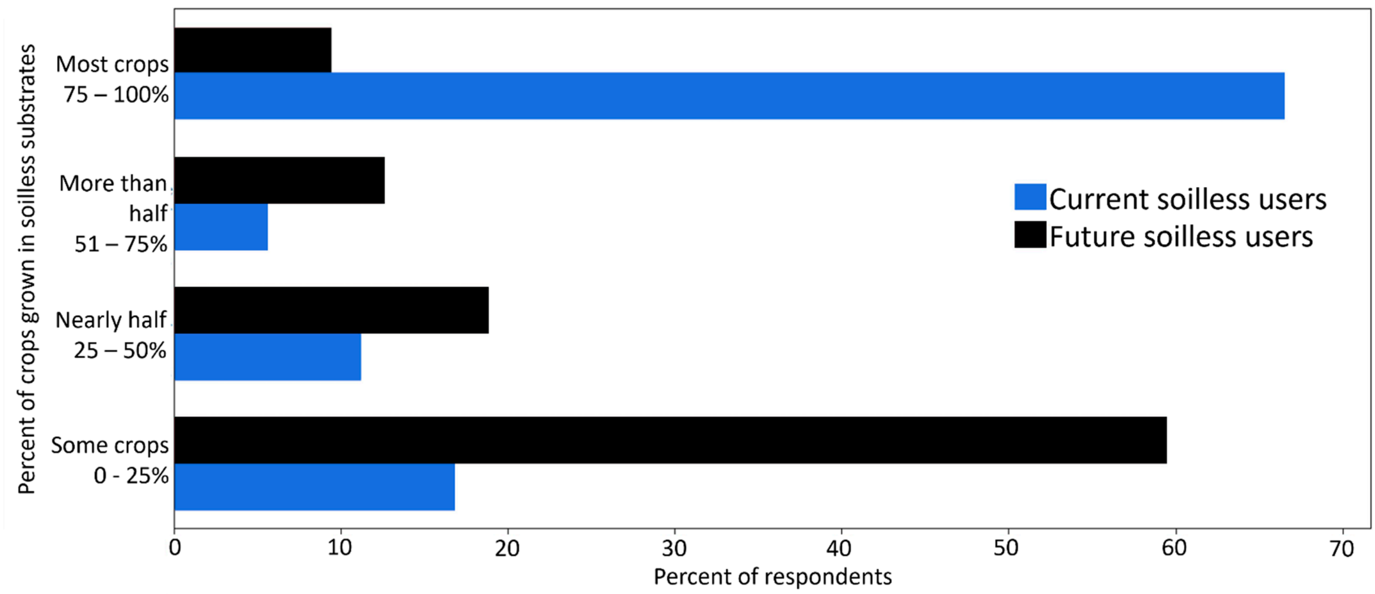

Figure 2. Percentage of production operations engaged in soilless culture for both current and future soilless producers.

Respondents who indicated they did not currently use soilless substrates were also asked what percentage of crops they believed they would grow on soilless substrates over the next five years if they were to adopt soilless substrate systems. Over half of respondents who were interested in soilless culture as an option expected to grow <25% of their crops on soilless substrates over the next five years (Figure 2), indicating a gradual adoption was more likely than a large-scale shift. This gradual transition can be attributed to the upfront costs in new equipment, new products, or transitioning current irrigation technology systems [9]. Conversely, if a grower already utilizes soilless culture, they were likely (nearly 67% of current users) to utilize soilless substrates for the majority or all (>75%) of their production. Few growers utilized soilless culture for small (<50%) portions of their growing operations, and very few growers utilized soilless culture for between 50% and 75% of their production (5% of current soilless growers).

When asked to indicate the importance of several factors using a five-point Likert-type scale in their decision to adopt or not adopt the use of soilless substrates, respondents indicated the most important factors were improving overall plant quality (M = mean, SD = standard deviation; M = 4.35, SD = 0.82), disease management (M = 4.15, SD = 0.96), and reducing shrinkage (or crop loss; M = 4.02, SD = 1.00). Respondents who indicated other concerns were concerned about the substrate being sustainable and organic (Figure 3). This is a popular topic in soilless substrate science, considering the perseverance and continued use of a substrate are crucial for the success of the industry. Frequent concerns about substrate sustainability include disposal post-production (i.e., rockwool in greenhouse production) [25], availability of peat, bark, and wood-based materials [26], and viability in real production conditions (i.e., resource efficiencies and impact on plant performance) [27].

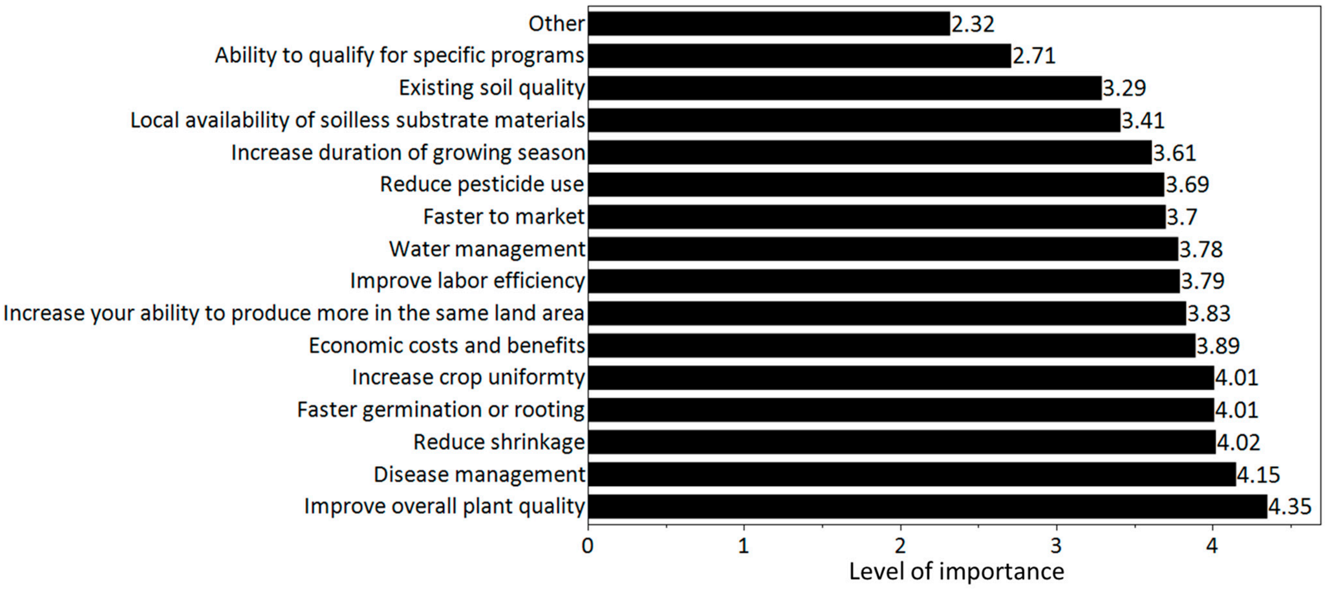

Figure 3. Response of 180 specialty crop producers when surveyed on the importance of factors in adopting soilless substrates. Level of importance was indicated by responses on a five-point Likert-type scale (1 = not important at all; 2 = slightly important; 3 = moderately important; 4 = very important; 5 = extremely important).

Respondents were also asked to indicate the importance of research needs, again using a five-point Likert-type scale, to gather how new information gained would help their adoption or success using soilless substrates. On average, respondents indicated that all the listed factors were moderately important, very important, or extremely important. The most important factors were their effect on crop quality and uniformity (M = 4.23, SD = 0.89), fertilizer management (M = 4.07, SD = 0.99), and economic costs and benefits/return on investment (M = 4.04, SD = 0.98; Figure 4).

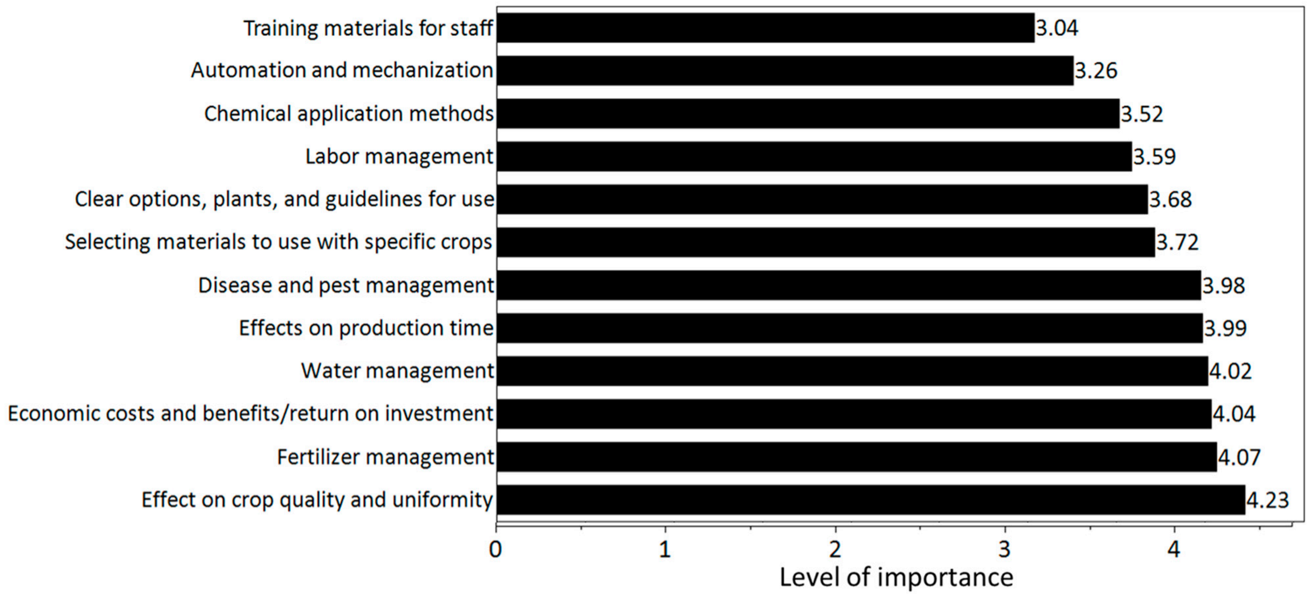

Figure 4. Response of 180 specialty crop producers when surveyed on the importance of research needs related to the use of soilless substrates. Level of importance was indicated by responses on a five-point Likert-type scale (1 = not important at all; 2 = slightly important; 3 = moderately important; 4 = very important; 5 = extremely important).

Survey respondents believed specific advantages would result from using soilless substrates (with the total number of indications in parentheses), including increased production quality (29), increased uniformity (26), reduced pest and disease pressure (23), reduction in labor and crop time (16), environmental sustainability (14), increased control (12), reduced cost (9), and new crop options (9). These advantages are scientifically supported by many [1,9]. Labor shortages continue and intensify in the United States, especially after the COVID-19 pandemic [28], where [29] et al. (2014) predicted stagnant employment percentages in the 2020s. Considering soilless cultivation reduces labor and crop cycles [1], soilless cultivation may provide a plausible adjustment to the current decrease in workforce populations. Conversely, survey respondents were asked to describe challenges their businesses may face with the incorporation of soilless substrates. The responses included initial investment (35), availability (16), learning curve and information availability (16), water management decisions (16), consistency (11), local access (8), and customer perceptions (3). These challenges associated with the adoption of soilless substrate systems have been previously discussed and continue to be an important focus of horticultural research [1,9].

3.2. Focus Groups

Focus group participants were also asked to identify the most important soilless substrate research needs. The results can be viewed in Table 1. All topics were important, though there were three that seemed to be of major importance amongst the growers participating in the focus groups: effect on crop quality and uniformity; water management; and fertilizer management (Table 1), which we have elected to discuss in greater depth. Information accessibility was teased out as a ninth priority and discussed separately.

Food safety and crop quality are primary concerns in soilless culture production [30]. In both the grower survey and focus groups, crop quality and uniformity were among the highest-scored responses and have already been assessed as major advantages for transitioning to soilless production [31]. Gruda [30] identified the number of researchers who have shown increased crop quality for tomatoes grown in soilless culture systems. A need for overall crop quality improvement was the top-ranked factor for potential adoption of soilless growing systems in every crop sector and every geographical region surveyed.

Table 1. Focus group participants' most important soilless substrate research needs for North American specialty crop producers.

Area	West	East	Total
Effect on crop quality and uniformity	4	5	9
Fertilizer management	3	5	8
Water management	4	4	8
Economic costs/benefits; ROI	2	4	6
Effect on production time	0	4	4
Disease and pest management	0	3	3
Labor management	0	1	1
Selecting materials to use with specific crops	0	1	1
Clear options, plans, and guidelines for use	0	0	0

When dealing with edible crops, food safety was considered extremely important from both regulatory and consumer perception standpoints. Consumers are highly focused on food safety [32], which relates directly to public health safety [33]. Reducing food safety concerns was expressed as a benefit of using soilless substrates. One grower mentioned "*We know it starts clean and stays clean*". The grower liked the added security of limiting potential foodborne pathogens in the soilless systems, insisting that utilizing soilless production "*prevents us from having to put a lot of extra units, like a UV [sterilizer] or anything like that. So, we know that as long as our substrate is coming in clean, we are good*". Another participant shared a similar perspective: "*It [soilless production] made the food safety side a lot easier*". Growers further indicated that many concerns with food safety rules were alleviated simply by growing on soilless substrates. One participant stated, "*You didn't have to worry about it [crop] coming in contact with the soil. You're 95% grade A and a whole lot less off-grade stuff*".

Growers indicated they are attentive and cautious about substrate materials that may be latent with heavy metals that could be available and hyper-accumulated in food crops. For example, one participant explained, "*For us, there is a concern with heavy metals, especially coming in with peat moss*". Growers indicated this concern could be due to the different substrate sources or harvest locations. Specifically, one participant indicated that "*it is a concern of ours in terms of food products and safety with that peat moss and where it comes from*". Previous studies have identified soilless systems, with peat moss in particular, that reduce the likelihood of trace metals in food crops [34]. However, peat is a viable sorbent for heavy metals [35].

Crop uniformity is a necessity for highly productive operations, especially since individual care cannot be afforded to specific plants. Instead, large groups or blocks must be grown equally, so crop quality will not be discounted. Consumers are becoming more selective and tend not to support low-quality products [36]. Thus, growers must produce crops with uniform vigor and phenotype for customers to know they are getting a similar product each time they purchase. In view of this, the soilless substrate used to produce these crops must be uniform and consistent [37] to produce consistent products.

Soilless substrate components and subsequent mixed product consistency and uniformity are also concerns. One participant summarized that we need "*more [research] about the uniformity of the substrates [...] that's going to translate into the uniformity of the crop*". Another participant stated, "*I think developing a consistent blend [...] that's really key in getting uniformity*". An additional participant indicated, "*Uniformity gives you predictability, gives you confidence in your numbers. So, I think that we're all in today's world with all the economic impacts, and no matter what crop you're growing, those are always at the front end of your mind at every planting*". Yet another participant expressed their experiences with substrate consistency: "*What I've learned is that when the substrate is extremely consistent, it's really wonderful to work with*".

Water and fertilizers have among the greatest impacts on crop growth and yield when considering grower-supplied inputs. Thus, there is substantial interest in water and fertility management and specifically in its sustainability and application [9]. Water resource management, especially related to environmental concerns, were of greater importance to participants in western North America than those in eastern North America. Data supports these concerns, as water use in agriculture is under scrutiny in the western U.S. [38]. However, water policies and limitations are becoming prevalent nationally. Fulcher et al. (2016) [24] reported that some growers claimed they used 47 to 56 million L ha^{-1} y^{-1}. Moreover, if growers are applying overhead sprinkler irrigation, >75% of the applied water can land within the inter-container spaces, further exacerbating wasteful water use [39].

Many outdoor container production operations use porous bark-based substrates with a constant supply of mineral nutrients from controlled-release fertilizers. The two most limiting crop nutrients, nitrogen and phosphorus (commonly in the form of nitrate and phosphate), move through soilless substrates quickly and rapidly leach from containers [40]. The leaching of nitrogen, phosphorus, and possibly pesticides can increase costs, reduce profit, and exacerbate environmental pollution [41]. One participant stated, "*The biggest issue is leaching. How much water goes in the pot? How much water comes out of the pot? What goes with the water when the water leaves the pot?*" Nursery runoff has received considerable attention in horticultural research, where runoff of nutrients or agrochemicals [42] can be reduced by using 'best management practices' [43], such as irrigating crops based on plant water use [44], utilizing conservative [45] or cyclical [46] irrigation scheduling, or by achieving a desired leaching fraction [47].

Focus group participants were most interested in matching substrates to watering conditions. One participant shared, "*I'm a big believer that your substrate choice should mirror your ability to irrigate. Whether you're flood irrigating, boom irrigating, or drip irrigating, whatever your irrigation platform is, you should match your substrate to do the best job with that, which can create a ton of variability*". In addition to substrate choice, container size and spacing have considerable influence on irrigation efficiency and uniformity. For instance, overhead irrigation is the most efficient delivery method for containers < 26.5 L, and drip irrigation is more efficient for containers > 25.6 L [24] when balancing labor and resource costs. Within a different growing context, an additional participant described how their different plants "*react very differently in different kinds of substrate based on the air to water ratio*". The specialty crop industry produces a broad diversity of crops. Lea-Cox and Smith [48] stated that there is no single substrate that can support all types of containerized crops. However, some soilless substrates, due to their limited water holding capabilities and low initial mineral nutrient content, provide ample flexibility to easily modify air-to-water ratios (i.e., incorporation of different substrates) or change mineral nutrient concentrations (i.e., applying different types or rates of fertilizer).

Focus group participants also discussed fertilizer management, which was of equal importance in both the eastern and western North American discussions. One participant indicated, "*I myself would like to see how can we get more out of the crop with less [fertilizer], really? I think, again, that goes back to the quality of the mix. How does the mix best make use of that fertilizer? I mean, we don't put fertilizer in just for kicks; I mean, it's a tool to serve a purpose*". A second participant stated, "*Managing the nutrition, I think that's something that every grower around the country is interested in, I would guess, because of the leaching and pollution and runoff*". It is evident that growers are conscious of their environmental impact [41] and believe that better fertility management is imperative for the welfare of ecological systems. Nutrient-enriched waterways from agricultural runoff, for example, the Mississippi River leading into the Gulf of Mexico, create 'dead zones' that intensify algal blooms [49]. Minimizing mineral nutrient leaching from an environmental viewpoint should, thus, be a foundation for the sustainability of specialty crop production. Another participant expressed an interest in "*adding a media that would reduce the leaching of the nutrient, keeping the EC lower to use the fertilizer because of that*". Additionally, another participant stated, "*There's always a lot of luxury fertilizer going around, and we really want to keep an eye on that and make sure we're only feeding as much as we need to. So being able to dial that in with a very reliable substrate is beneficial at high scale, big scale*".

Another aspect of sustainability, economic impact, relates to fertilizer costs, especially at large-scale nursery operations. A substrate management strategy that can serve as an effective tool to reduce fertilizer inputs and thereby reduce associated fertility costs is a focal point of soilless substrate science research. Focus group participants also discussed improving fertilizer management and reducing the environmental impact of runoff and nutrients. For example, one participant stated, "*For us, it's the amount of nutrient runoff that we get out of our substrate is an issue, and that would be of interest*". Some growers capture and recycle their nutrient runoff waste by reapplying it as irrigation water, which can generate cost savings with regards to water use [50]. However, Abdi and Fernandez [42] state that there are concerns with agrochemicals, such as pesticides, in the captured water, and it may be necessary to remove those chemicals.

Disease and pest management were also identified as important factors in adoption. Beyond food safety, the perceived lack of plant pathogens was continually discussed as a primary driver for transitioning to soilless culture. One participant explained "*Virus-free growing and virus-free facilities are very important [. . .] you're also able to control a lot of pathogens*". An additional grower indicated they have been "*transitioning from soil-grown crops with a lot of methyl bromide and field-grown roots to the substrate portion for probably a little over five years [. . .] because they don't have any way to maintain the cleanliness of the soil grown pathogens and stuff without the bromide*". Unlike field production, soilless culture allows nearly complete control over what is introduced to the growing media and surrounding area, where added measures can be taken to clean inputs [51] and the spread of disease is reduced by the individuality of each container plant, supporting healthy growing environments [52]. Growers can ensure that plants are grown with initially disease-free media through quality control efforts and selective sourcing. A grower mentioned "*you're able to control a lot of pathogens*," indicating additional disease control with the implementation of soilless culture, as was the original goal of the system when introduced in the 1950s [53].

Improved consumer perception was discussed as both a benefit and a challenge to adoption. It is necessary that consumers accept crops produced in soilless substrate systems to better facilitate the transition to those systems. The ultimate goal of specialty crop producers is to sell their product, and it is known that consumers are becoming more selective in what they purchase [54]. One participant shared that "*each operation has to find their balance of what customers are willing to accept*". Consumers are becoming increasingly focused on sustainable production practices for their agricultural commodities [55]. While many perceive soilless systems as artificial when compared to field production, the perception of soilless culture as a sustainable practice is rising [56], with added opportunities to further extend sustainability [27].

One participant shared that soilless substrates improved "*consumer perception of something that the consumer still considers to be dirt*". There are many reasons for the improved perception of soilless production, including reductions in fumigants and agrichemical use [57], increased water and fertilizer efficiency [58], and improved soil health [8]. In a review of soilless culture, Putra and Yuliando [59] similarly identified the absence of soil-borne pathogens, increased nutrient and water efficiency, and increased yield as the primary benefits associated with soilless production. Growers indicated the reduction in chemicals as a major selling point to consumers. For example, one participant stated, "*With the reduced use of chemical treatments such as methyl bromide in soil growing conditions, the perception that soilless substrates were virus-free was also seen as a benefit*".

There was also the theme of disposal, including substrate and supplies needed when producing in soilless culture. Growers identified the added waste accumulation that may occur with soilless substrates when compared to field production as a significant challenge for soilless substrate adoption. Traditional field growers can soil-incorporate any culled materials; however, soilless users have items like plastic containers that make disposal more difficult. While there are environmentally friendly biodegradable container options [60,61], these may not be available or cost-efficient for large-scale production [62]. Furthermore, many biodegradable containers have issues with water efficiency and temperature fluctuations [63], as well as longevity to support long-term production [64]. Another aspect of disposal involves the substrate itself. When a crop or its fruit is harvested, some soilless substrates can be recycled, while others are commonly disposed of. Many, but not all, of the soilless substrates used in North American agriculture are organic in nature [65]. As a result, substrates such as bark and peat typically do not have disposal issues.

Participants in the focus groups specifically identified rockwool disposal as associated with increasing expenditures, as they must pay to dispose of similar synthetic materials. One grower stated, "*We have to pay more to dispose of it [rockwool] than any peat-based substrate*". Moreover, the disposal of rockwool has been identified as a potential ecological issue when disposed of in landfills due to the inert nature of the material [66]. While many synthetic materials can be recycled and reused [67], these options are often neither pragmatic nor cost-effective for rockwool [68].

Understanding the logistics of transportation and shipping was identified as an advantage for transitioning to soilless substrates. Participants felt that reduced weight and subsequent shipping benefits were a strong reason to shift to soilless systems. While soils have an average bulk density of 1.33 g cm^{-3}, soilless substrate bulk density typically ranges from 0.1 to 0.2 g cm^{-3} (for peat and pine bark, respectively). For example, in one focus group, a grower expressed that when they ship in less dense soilless materials, their customers have indicated that "*they appreciate being able to get a full load*". Ease of transportation has long been identified as a primary driver in the shift to containerized production [69]. Soilless culture opens up avenues for the production of crops (ornamental, edible, and cut flowers) year-round globally, which increases the need for shipping plant material over greater distances. The use of relatively lightweight soilless media (lower bulk density compared to mineral soils) lowers the overall container weight, thus increasing the quantity that can be included in a shipment.

Participants decidedly identified economics, especially the return on their initial investment, as the primary challenge to the adoption of soilless substrate systems. Many respondents to the grower survey were interested in any information that could increase their profits. While initial investment and infrastructure costs are obvious factors in shifting to soilless production, there has been little research on the costs associated with a field-based to soilless culture transition. Within soilless culture, growers participating in the focus groups indicated they were willing to pay a premium for high-quality soilless substrates, especially if they came with better growing practices or supported more uniform crops. One participant shared, "*If you have 25 cents, spend 20 cents on soil, and 5 cents on your seed*". Another participant commented, "*The quality of the substrate pays for itself when it results in good crop uniformity*". Yet another stated, "*The cost management of the media isn't so much as the overall [cost of] being able to produce a product within the limits the government is giving us at this point*", alluding to the relatively low cost of media in production. Another participant agreed, "*The money that you spend on a good substrate always outweighs the cost savings that you would get from cheap substrate*".

While material costs and labor are important drivers in decisions made by specialty crop producers, growers participating in the focus groups indicated they were willing to pay a premium on substrates if they provided identifiable benefits in production or improved crop quality.

Accessibility of Information to Growers

Growers in both the survey and the focus groups consistently expressed the need for information that is easily accessible. Information availability was also mentioned as the second-greatest challenge to adoption or transitioning to soilless substrate systems.

There seems to be a disconnect between North American growers and academic research when it comes to soilless substrate science. One participant stated that "*You are trying to use a one-size-fits-all approach to irrigation over 500 different crops over a large area. Real specific or hyper-specific information is sometimes more frustrating than anything*". While researchers may attempt to conduct applicable research, the information provided may not always be directly transferable to the grower. One of the primary goals of extension is to keep farmers informed of new techniques and provide directly applicable instruction [70], thus transferring very specific research results to a broad grower audience with varying needs is a challenge that needs to be addressed.

It is critical to ensure that continued communication and knowledge exchange are facilitated between growers and researchers. Within the focus groups, participants discussed the overall lack of soilless substrate research available compared to industry needs. One participant noted, "*One of the things that we are struggling with when you're dealing with all the substrates is identifying the exact properties of the ingredients*". A participant described, "*I did not go to school for what I am doing, and I am just trying to figure it out based on my experience, and sometimes I have difficulty knowing what's the best combination of soils and waters and fertilizers to come together to make the most economic and the most effective product in the end. Just understanding how all of those things interact together is a real challenge, for me anyway. So that is really what I am looking for in this subject is just understanding the physical properties and the qualities of the mix and how it ties all these other things together*". Another participant shared a similar experience: "*I would love to be able to deconstruct or break down a mix that is performing ideally for us to understand what that is so that we can then work towards replicating that more consistently*". It is apparent that there is a need for several elaborate yet straightforward summary articles discussing the popular soilless substrates, their physio-chemical properties, and their reactions to different irrigation and fertilizer management practices.

A number of representative North American growers indicated that they primarily seek European resources for soilless substrate decisions. Many major growers were seeking outside information that may not align with the materials or production methods they are utilizing. A participant found that "*Once you go way from these defined materials [European peat], it becomes very, very difficult to really get that information in depth*". Thus, North American standards are of great importance and are not easily found. Regional and crop- and production-practice-specific standards are crucial for the continued success of North American soilless specialty crop production. Growers need information that directly applies to their operations. Substrate formulations, especially those created by individual growers, vary widely in materials, properties, and processing across North America. Growers in more arid regions cannot follow the same standards as growers in more temperate regions.

Growers continually asked for comprehensive, North-American-based research, specifically geared towards growers, that was not generated in tightly controlled laboratory conditions. For example, one participant described their experience trying to locate and use soilless substrate research and how they have "*seen some great research come out, out of research stations and so on, but it's under lab conditions*". Growers acknowledged that they primarily relied on a few academic institutions but were heavily reliant on European institutions and suppliers. One participant stated frankly, "*I go to the Netherlands*". A second participant indicated they attended a university in Europe and stated, "*I contact some of my old classmates, and they seem to be so far ahead. The key is being able to make the translation to what information is available in Europe and how to apply it here*". One participant explained how it "*would really be helpful if there would be a university here in the US that would . . . do some of those translations for me . . . that's where I see a lot of mistakes being made is people trying to directly use European knowledge and apply it here*".

Participants also expressed interest in secondary sources of information, specifically practitioner knowledge. One participant shared that it is "*important that you stay in touch with the mom-and-pop operations. There are just volumes of institutional knowledge and the more that you have outreach folks communicating with them and folks massaging and translating those messages from low-tech to high-tech*". This perspective was reinforced by another participant: "*There's really nothing I go to or have to go to other than just individual universities or Cultivate. So, I think sign up for a newsletter updates [. . .] maybe a social media platform*". Another participant also described their interest in a comprehensive data source they could use to investigate and inform their soilless substrate choices: "*If somebody would write a really good textbook for* *growers on soil science and plant nutrition and the interaction of plant nutrition and water and soil, I think it would be something that every grower would buy*".

4. Conclusions

Many specialty crop growers have either considered or are considering adopting soilless substrates as part of their crop production methods. The needs assessment conducted provides information on growers' perceptions of the magnitude of this need now and in the future. Nearly 70% of growers that currently utilize soilless substrates do so almost exclusively. However, of the growers that indicated potential adoption, 60% indicated only a maximum of a 25% shift to soilless culture. The finding implies that while transition is considered, it would only be for select aspects of production. Field-grown specialty crop producers were generally comfortable with their current practices. However, the survey results indicate that, in time, the soilless substrate community will have to expand to support new and alternative growing efforts.

The results of the survey and focus groups demonstrated that research and extension are needed to successfully assist the specialty crop industry already utilizing or transitioning to soilless culture. This research needs to be focused but applicable to ensure it will best support grower needs. Moreover, it is imperative that research and extension professionals continue to build bridges and develop outreach efforts with growers to train, educate, and share knowledge so that the work done will continue to be impactful.

Author Contributions: Conceptualization, J.S.F., J.S.O.J., B.J. and J.A.; formal analysis, A.L.; funding acquisition, J.S.F., J.S.O.J., A.L., J.A., B.J., L.O., J.B.S. and Y.Z.; investigation, A.L.; methodology, A.L.; project administration, J.S.F.; writing—original draft, J.S.F.; writing—review and editing, J.S.F., J.S.O.J., K.S.C., J.A., B.J., L.O., J.B.S. and Y.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the Specialty Crops Research Initiative Planning Grant no. 2020-51181-32141 from the USDA National Institute of Food and Agriculture.

Institutional Review Board Statement: This research was approved as exempt under UGA PROJECT #00000272.

Data Availability Statement: Data are available upon request due to privacy restrictions.

Acknowledgments: The willingness of so many growers to not only support but also participate in research to move knowledge-based agriculture forward was greatly appreciated. In all aspects of this research, growers were more than willing to take time from their busy schedules to answer questions, discuss ideas, and help steer the research project to not only benefit their operations but the industry as a whole. The authors of this paper would like to express our deepest thanks to all of the individuals and operations that supported this needs assessment and continually progressed our understanding of soilless substrate science. It is important to note that the ideas and outcomes discussed in this manuscript reflect the survey and focus group results and are not the opinions of the authors.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Gruda, N. Soilless Culture Systems and Growing Media in Horticulture: An Overview. In *Advances in Horticultural Soilless Culture*; Gruda, N.S., Ed.; Burleigh Dodds Science: Cambridge, UK, 2021; pp. 1–20.
2. Detweiler, M.B.; Sharma, T.; Detweiler, J.G.; Murphy, P.F.; Lane, S.; Carman, J.; Chudhary, A.S.; Halling, M.H.; Kim, K.Y. What Is the Evidence to Support the Use of Therapeutic Gardens for the Elderly? *Psychiatry Investig.* **2012**, *9*, 100–110. [CrossRef] [PubMed]
3. Landis, T.D.; Tinus, R.W.; McDonald, S.E.; Barnett, J.P. Containers and growing media. In *The Container Tree Nursery Manual*; Agricultural Handbook 674; U.S. Department of Agriculture, Forest Service: Washington, DC, USA, 1990.
4. U.S. Department of Agriculture. 2017 Census of Agriculture, 2019 Census of Horticultural Specialties. In *N.A.S. Service*; U.S. Department of Agriculture: Washington, DC, USA, 2020; p. 1.
5. Blok, C.; Eveleens, B.; van Winkel, A. Growing media for food and quality of life in the period 2020–2050. *Acta Hortic.* **2021**, *1305*, 341–355. [CrossRef]

6. Claire, D.; Watters, N.; Gendron, L.; Boily, C.; Pépin, S.; Caron, J. High productivity of soilless strawberry cultivation under rain shelters. *Sci. Hortic.* **2018**, *232*, 127–138. [CrossRef]
7. Kingston, P.H.; Scagel, C.F.; Bryla, D.R.; Strik, B. Suitability of sphagnum moss, coir, and douglas fir bark as soilless sub-strates for container production of highbush blueberry. *HortScience* **2017**, *52*, 1692–1699. [CrossRef]
8. Sambo, P.; Nicoletto, C.; Giro, A.; Pii, Y.; Valentinuzzi, F.; Mimmo, T.; Lugli, P.; Orzes, G.; Mazzetto, F.; Astolfi, S.; et al. Hydroponic Solutions for Soilless Production Systems: Issues and Opportunities in a Smart Agriculture Perspective. *Front. Plant Sci.* **2019**, *10*, 923. [CrossRef] [PubMed]
9. Raviv, M.; Leith, J.H. *Soilless Culture Theory and Practice*; Elsevier: San Diego, CA, USA, 2008.
10. UN. The Worlds Cities in 2018. 2018. Available online: https://www.un.org/events/citiesday/assets/pdf/the_worlds_cities_in_2018_data_booklet.pdf (accessed on 28 August 2023).
11. Tremblay, M.A. The key informant technique. *A non-ethnographic application. Am. Anthropol.* **1957**, *59*, 688–701.
12. Gibson, K.E.; Lamm, A.J.; Masambuka-Kanchewa, F.; Fisher, P.R.; Gómez, C. Identifying Indoor Plant Propagation Research and Education Needs of Specialty Crop Growers. *HortTechnology* **2020**, *30*, 519–527. [CrossRef]
13. Ary, D.; Jacobs, L.C.; Sorensen, C.K.; Walker, D.A. *Introduction to Research in Education*; Wadsworth Cengage Learning: Belmont, CA, USA, 2014.
14. Chalofsky, N. *How to Conduct Focus Groups*; American Society for Training and Development: Alexandria, VA, USA, 1999.
15. Lincoln, Y.S.; Guba, E.G. Judging the quality of case study reports. In *The Qualitative Researcher's Companion*; Huberman, A.M., Miles, M.B., Eds.; Sage Publication: Thousand Oaks, CA, USA, 2002; pp. 205–216.
16. Creswell, J.W.; Creswell, J.D. *Research Design: Qualitative, Quantitative, and Mixed Method Approaches*; Sage Publication: Thousand Oaks, CA, USA, 2017.
17. Sandelowski, M. Combining qualitative and quantitative sampling, data collection, and analysis techniques in mixed-method studies. *Res. Nursing Health* **2000**, *23*, 246–255. [CrossRef]
18. Bazeley, P. Integrative Analysis Strategies for Mixed Data Sources. *Am. Behav. Sci.* **2011**, *56*, 814–828. [CrossRef]
19. White, A.S. From Nursery to Nature: Evaluating Native Herbaceous Flowering Plants versus Native Cultivars for Pollinator Habitat Restoration. 2016. A Dissertations. The University of Vermont. Available online: http://proxy.lib.ohio-state.edu/login?url=https://www.proquest.com/dissertations-theses/nursery-nature-evaluating-native-herbaceous/docview/1805944753/se-2 (accessed on 28 August 2023).
20. Bevan, L.; Jones, M.; Zheng, Y. Optimisation of Nitrogen, Phosphorus, and Potassium for Soilless Production of Cannabis sativa in the Flowering Stage Using Response Surface Analysis. *Front. Plant Sci.* **2021**, *12*, 2587. [CrossRef]
21. Summers, H.M.; Sproul, E.; Quinn, J.C. The greenhouse gas emissions of indoor cannabis production in the United States. *Nat. Sustain.* **2021**, *4*, 644–650. [CrossRef]
22. Zheng, Y. Soilless production of drug-type Cannabis sativa. *Acta Hortic.* **2021**, *1305*, 376–382. [CrossRef]
23. Knight, A. Towards Sustainable Growing Media. Chairman's Report and Roadmap, Sustainable Growing Media Task Force. 2012. Available online: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/221019/pb13867-towards-sustainable-growing-media.pdf (accessed on 28 August 2023).
24. Fulcher, A.; LeBude, A.V.; Owen, J.S.; White, S.A.; Beeson, R.C. The Next Ten Years: Strategic Vision of Water Resources for Nursery Producers. *HortTechnology* **2016**, *26*, 121–132. [CrossRef]
25. Fields, J.S.; Gruda, N.S. Developments in inorganic materials, synthetic organic materials and peat in soilless culture systems. In *Advances in Horticultural Soilless Culture*; Gruda, N.S., Ed.; Burleigh Dodds Science: Cambridge, UK, 2021.
26. Gruda, N.S.; Bragg, N. Developments in alternative organic materials for growing media in soilless culture systems. In *Advances in Horticultural Soilless Culture*; Gruda, N.S., Ed.; Burleigh Dodds Science: Cambridge, UK, 2021.
27. Barrett, G.E.; Alexander, P.D.; Robinson, J.S.; Bragg, N.C. Achieving environmentally sustainable growing media for soilless plant cultivation systems—A review. *Sci. Hortic.* **2016**, *212*, 220–234. [CrossRef]
28. Karan, E.; Asgari, S. Resilience of food, energy, and water systems to a sudden labor shortage. *Environ. Syst. Decis.* **2021**, *41*, 63–81. [CrossRef] [PubMed]
29. Levanon, G.; Cheng, B.; Paterra, M. The Risk of Future Labor Shortages in Different Occupations and Industries in the United States. *Bus. Econ.* **2014**, *49*, 227–243. [CrossRef]
30. Gruda, N. Do soilless culture systems have an influence on product quality of vegetables? *J. App. Bot. Food Qual.* **2009**, *82*, 141–147.
31. Massantini, F.; Favilli, R.; Magnani, G.; Oggiano, N. Soilless culture-biotechnology for high quality vegetables. *Soil. Cult.* **1988**, *4*, 27–40.
32. Verbeke, W. Agriculture and the food industry in the information age. *Eur. Rev. Agric. Econ.* **2005**, *32*, 347–368. [CrossRef]
33. Gizaw, Z. Public health risks related to food safety issues in the food market: A systematic literature review. *Environ. Health Prev. Med.* **2019**, *24*, 68. [CrossRef]
34. Pennisi, G.; Orsini, F.; Gasperi, D.; Mancarella, S.; Sanoubar, R.; Antisari, L.V.; Vianello, G.; Gianquinto, G. Soilless system on peat reduce trace metals in urban-grown food: Unexpected evidence for a soil origin of plant contamination. *Agron. Sustain. Dev.* **2016**, *36*, 56. [CrossRef]
35. Balan, C.; Bulai, P.; Bilba, D.; Macoveanu, M. Sphagnum moss peat: A green and economical sorbent for removal of heavy metals (Cd and Cr) from wastewaters. *Environ. Eng. Manag. J.* **2010**, *9*, 469–477. [CrossRef]

36. Harker, F.; Gunson, F.; Jaeger, S.R. The case for fruit quality: An interpretive review of consumer attitudes, and preferences for apples. *Postharvest Biol. Technol.* **2003**, *28*, 333–347. [CrossRef]
37. Zheng, Y. Integrated rootzone management for successful soilless culture. *Acta Hortic.* **2020**, *1273*, 1–8. [CrossRef]
38. Howitt, R.; Medellín-Azuara, J.; MacEwan, D.; Lund, J.; Sumner, D. *Economic Analysis of the 2014 Drought for California Agriculture*; Center for Watershed Sciences, University of California: Davis, CA, USA, 2014.
39. Haman, D.; Yeager, H. *Irrigation System Selection for Container Nurseries*; University of Florida Cooperative Extension Service: Gainesville, FL, USA, 2010.
40. Hoskins, T.C.; Owen, J.S.; Fields, J.S.; Altland, J.E.; Easton, Z.M.; Niemiera, A.X. Solute Transport through a Pine Bark-based Substrate under Saturated and Unsaturated Conditions. *J. Am. Soc. Hortic. Sci.* **2014**, *139*, 634–641. [CrossRef]
41. Mack, R.; Owen, J.S.; Niemiera, A.X.; Sample, D.J. Validation of Nursery and Greenhouse Best Management Practices through Scientific Evidence. *HortTechnology* **2019**, *29*, 700–715. [CrossRef]
42. Abdi, D.E.; Fernandez, R.T. Reducing Water and Pesticide Movement in Nursery Production. *HortTechnology* **2019**, *29*, 730–735. [CrossRef]
43. Bilderback, T.E.; Owen, J.S., Jr.; Altland, J.E.; Fain, G.B.; Jackson, B.E.; Riley, E.D.; Kraus, H.T.; Fonteno, W.C. Strategies for developing sustainable substrates in nursery crop production. *Acta Hortic.* **2013**, *1013*, 43–56. [CrossRef]
44. Pershey, N.A.; Cregg, B.M.; Andresen, J.A.; Fernandez, R.T. Irrigation based on daily water use reduces nursery runoff volume and nutrient load without reducing growth of four conifers. *HortScience* **2015**, *50*, 1553–1561. [CrossRef]
45. Asrey, R.; Kumar, S.; Meena, N.K. Influence of water quality on postharvest fruit and vegetable quality. In *Preharvest Modulation of Postharvest Fruit and Vegetable Quality*; Siddiqui, M.W., Ed.; Academic Press: Cambridge, MA, USA, 2018; pp. 169–187.
46. Taylor, A.J.; Fernandez, R.; Nzokou, P.; Cregg, B. Carbon Isotope Discrimination, Gas Exchange, and Growth of Con-tainer-grown Conifers Under Cyclic Irrigation. *HortScience* **2013**, *48*, 848–854. [CrossRef]
47. Million, J.B.; Yeager, T.H. Leaching Fraction-based Microirrigation Schedule Reduced Water Use but Not N and P Loss during Production of a Container-grown Shrub. *HortScience* **2021**, *56*, 147–153. [CrossRef]
48. Lea-Cox, J.D.; Smith, I.E. The interaction of air-filled porosity and irrigation regime on the growth of three woody per-ennial (citrus) species in pine bark substrates. *Proc. South. Nurs. Assoc. Res. Conf.* **1997**, *42*, 169–174.
49. Bruckner, M. The Gulf of Mexico Dead Zone. Montana State Univ. Microbial. Life. Educ. Resources. 2019. Available online: https://serc.carleton.edu/microbelife/topics/deadzone/advanced.html (accessed on 28 August 2023).
50. Ferraro, N.; Bosch, D.; Pease, J.; Owen, J.S. Costs of Capturing and Recycling Irrigation Water in Container Nurseries. *HortScience* **2017**, *52*, 258–263. [CrossRef]
51. Acher, A.; Heuer, B.; Rubinskaya, E.; Fischer, E. Use of ultraviolet-disinfected nutrient solutions in greenhouses. *J. Hortic. Sci.* **1997**, *72*, 117–123. [CrossRef]
52. Schnitzler, W. Pest and disease management of soilless culture. *Acta Hortic.* **2004**, *648*, 191–203. [CrossRef]
53. Baker, K. The U.C. System for producing healthy container-grown plants: Through the use of clean soil, clean stock, and san-itation. *Calif. Agric. Exp. Stn. Man.* **1957**, *23*, 1–332.
54. Hall, C.R.; Campbell, B.L.; Behe, B.K.; Yue, C.; Lopez, R.G.; Dennis, J.H. The Appeal of Biodegradable Packaging to Floral Consumers. *HortScience* **2010**, *45*, 583–591. [CrossRef]
55. Isaak, M.; Lentz, W. Consumer Preferences for Sustainability in Food and Non-Food Horticulture Production. *Sustainability* **2020**, *12*, 7004. [CrossRef]
56. Muller, A.; Ferre, M.; Engel, S.; Gattinger, A.; Holzkamper, A.; Huber, R.; Muller, M.; Six, J. Can soil-less crop production be a sustainable option for soil conservation and future agriculture? *Land Use Pol.* **2017**, *69*, 102–105. [CrossRef]
57. Paranjpe, A.; Cantliffe, D.; Lamb, E.; Stoffella, P.; Powell, C. Winter strawberry production in greenhouses using soilless substrates: An alternative to methyl bromide soil fumigation. *Proc. Fla. State Hortic. Soc.* **2003**, *116*, 98–105.
58. Pignata, G.; Casale, M.; Nicola, S. Water and nutrient supply in horticultural crops grown in soilless culture: Resource efficiency in dynamic and intensive systems. In *Advances in Research on Fertilization Management of Vegetable Crops*; Springer: Cham, Germany, 2017. [CrossRef]
59. Putra, A.P.; Yuliando, H. Soilless culture system to support water use efficiency and product quality: A review. *Agric. Agric. Sci. Procedia* **2015**, *3*, 283–288. [CrossRef]
60. Knox, G.W.; Chappell, M. *Nursery Crop Selection and Market Niches*; University of Florida Cooperative Extension Services ENH1194/EP455; University of Florida: Gainesville, FL, USA, 2011.
61. Fulcher, A.; Cochran, D.R.; Koeser, A.K. An Introduction to the Impact of Utilizing Alternative Containers in Ornamental Crop Production Systems. *HortTechnology* **2015**, *25*, 6–7. [CrossRef]
62. Brumfield, R.G.; DeVincentis, A.J.; Wang, X.; Fernandez, R.T.; Nambuthiri, S.; Geneve, R.L.; Koeser, A.K.; Bi, G.; Li, T.; Sun, Y.; et al. Economics of utilizing alternative containers in ornamental crop pro-duction systems. *HortTechnology* **2015**, *25*, 17–25. [CrossRef]
63. Nambuthiri, S.; Fulcher, A.; Koeser, A.K.; Geneve, R.; Niu, G. Moving Toward Sustainability with Alternative Containers for Greenhouse and Nursery Crop Production: A Review and Research Update. *HortTechnology* **2015**, *25*, 8–16. [CrossRef]
64. Li, T.; Bi, G.; Niu, G.; Nambuthiri, S.; Geneve, R.L.; Wang, X.; Fernandez, R.T.; Sun, Y.; Zhao, X. Feasibility of using bio-containers in a pot-in-pot system for nursery production of river birch. *HortTechnology* **2015**, *25*, 57–62. [CrossRef]
65. Bar-Tal, A.; Saha, U.K.; Raviv, M.; Tuller, M. Inorganic and Synthetic Organic Components of Soilless Culture and Potting Mixtures. In *Soilless Culture: Theory and Practice*, 2nd ed.; Raviv, M., Lieth, J.H., Bar-Tal, A., Eds.; Academic Press: London, UK, 2019.

66. Bohme, M. Evaluation of organic, synthetic, and mineral substrates for hydroponically grown cucumbers. *Acta Hortic.* **1995**, *401*, 209–217. [CrossRef]
67. Yap, Z.S.; Khalid, N.H.A.; Haron, Z.; Mohamed, A.; Tahir, M.M.; Hasyim, S.; Saggaff, A. Waste material wool and its opportunities—A review. *Materials* **2021**, *14*, 5777. [CrossRef]
68. Kennard, N.; Stirling, R.; Prashar, A.; Lopez-Capel, E. Evaluation of Recycled Materials as Hydroponic Growing Media. *Agronomy* **2020**, *10*, 1092. [CrossRef]
69. Knox, G.W.; Chappell, M. *Alternatives to Petroleum-Based Containers for the Nursery Industry*; EDIS: Fort Bragg, NC, USA, 2014.
70. Jones, G.E.; Garforth, C. *Chapter 1—The History, Development, and Future of Agriculture Extension. Improving Agriculture Extension. A Reference Manual*; Food and Agriculture Organization of the United Nations: Rome, Italy, 1997; ISBN 92-5-104007-9.