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Relating Grower Perceptions and Adoption of Automated Nursery Technologies to Address Labor Needs

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Abstract

This study examined factors that shape how nursery growers perceive automated nursery technologies and evaluate how these perceptions relate to growers' adoption. We applied Rogers' (2003) Diffusion of Innovations to understand growers' perceptions of automated technologies to inform Extension programming serving niche audiences in the nursery and horticulture arenas. Data were collected via a mixed-mode survey and analyzed using descriptive statistics and multiple linear regression. Nursery growers indicated fairly strong perceptions of observability, relative advantage, and compatibility. Automated nursery technologies were not perceived as being complex. Notably, perceptions of trialability were low. Compatibility, complexity, and trialability predicted growers' current adoption of automated technologies. Relative advantage, complexity, and compatibility predicted the future adoption of automated nursery technologies. Compatibility was the most important predictor of both current use and the likelihood of adopting automated nursery technologies. Extension professionals, researchers, and others who support the nursery industry can use these findings to encourage the adoption of technological innovations. Chiefly, automated nursery technologies need to be designed with compatibility in mind (e.g., adaptable to nursery operations' existing infrastructure, values, and goals). Uptake could be accelerated by emphasizing compatibility (e.g., conveying how these technologies can be integrated into existing systems and how the current labor force's skillsets can be applied to new technologies). This study considered a suite of automated nursery technologies to provide a starting point in developing and diffusing these types of innovations. Future research should examine the characteristics of specific technologies to pinpoint precise strategies aimed at behavioral adoption.

Keywords: automation technologies; Diffusion of Innovations; Extension audience needs; Green Industry; nursery industry

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Introduction

Within the United States agriculture industry, the Green Industry sector entails the producing, selling, and installing of trees, shrubs, vines, and herbaceous perennial and annual plants and is vitally important to the U.S. economy. In 2018, the U.S. Green Industry had a direct industry output of $159.6 billion with total output contributions reaching approximately $348 billion (Hall et al., 2020). The Green Industry directly employed nearly 1.6 million full-time and part-time employees with total employment contributions of over 2.3 million jobs in the broader economy (Hall et al., 2020). Landscape and horticulture service firms accounted for the largest portion of jobs and GDP contributions, followed by greenhouse, nursery, and floriculture production firms. By itself, U.S. greenhouse, nursery and floriculture production firms accounted for 217,574 jobs and contributed $28.9 billion to the GDP (Hall et al., 2020). Considering all sectors of the Green Industry, the number of jobs has increased 16.2% since 2013 while the GDP increased 17.3%.

While the Green Industry is a vital component of agriculture in the United States, it is not without challenges. This sector is labor-intensive and relies on a full-time workforce augmented by seasonal workers (Astill et al., 2020). In a 2019 report, 92% of businesses indicated that it was extremely or somewhat difficult to find good employees and attracting and retaining employees was their most frequent concern (HindSite Software, 2019). Ironically, less than 15% recognized that inefficient processes might play a role in their labor shortage (HindSite Software, 2019). Automation technologies can address this gap by improving overall productivity and worker health and job satisfaction (Grift et al., 2008). To date, seasonal laborers and the impact of immigration policy has often been featured in the mass media and research spotlights (Astill et al., 2020; Wright, 2021); however, 71,000 full-time positions remained vacant in 2017 (Hyatt Presley, 2019), indicating the need for additional workers or alternative production methods (such as automation) to address these unmet labor needs.

Implications of the current labor shortage affect all areas of the Green Industry, driving the need to find more efficient processes. Amidst increasing demand for trees, shrubs, and other ornamental plants for the landscape (Garden Research, 2021), all sectors of the Green Industry are experiencing a labor shortage that is negatively impacting day-to-day operations. For example, 77% of nurseries stated that labor is their most significant business challenge and 51% said the lack of qualified labor limited hiring (McClellan, 2018). In addition, members of the Green Industry have indicated that labor scarcity is the most substantial impediment to growth (Hyatt Presley, 2019). Collectively, these challenges suggest significant limitations to the long-term viability of the Green Industry.

Scarcity, uncertainty, and the high cost of both domestic and foreign labor are driving interest in mechanizing and automating nursery production tasks. Mechanization and automation and related technologies, collectively referred to as automation for simplicity in this paper, may allow nursery producers to not only maintain day-to-day productivity, but also expand operations with a reduced work force and use their limited work force most effectively and efficiently (Astill et al., 2020; Grift et al., 2008). Many nursery tasks are repetitive; thus, automation affords the opportunity to perform the tasks more uniformly and reallocate the limited workforce to tasks that require more mental agility and present a lower threat of stress injuries for workers. Additionally, many production tasks are time-sensitive and accomplishing those tasks in a shorter time frame can help ensure they occur at the optimum time in the production schedule, deploy labor most effectively, and yield consistent crops that develop their marketable attributes during the intended sales window. Researchers and Extension professionals can serve the Green Industry by helping to identify solutions to labor challenges. Automated nursery technologies offer potential and promising solutions.

The overall objective of this research was to investigate growers' perceptions and adoption of automation technologies. The Diffusion of Innovations (DOI) (Rogers, 2003) was employed to address this research objective. The next section briefly describes the theoretical framework of the study, followed by the methods, results and discussion.

Theoretical Framework

The Diffusion of Innovations (DOI) (Rogers, 2003) guided this research. This theory clarifies a social group's adoption of innovations through the social system itself, the specific innovation, the period during which diffusion takes place, and the channels through which the innovation is communicated. In addition, DOI explains the adoption process and elucidates perceived characteristics of innovations influencing adoption. DOI also categorizes people into adopter categories (e.g., innovators, early adopters, etc.). The following provides a brief overview of these areas.

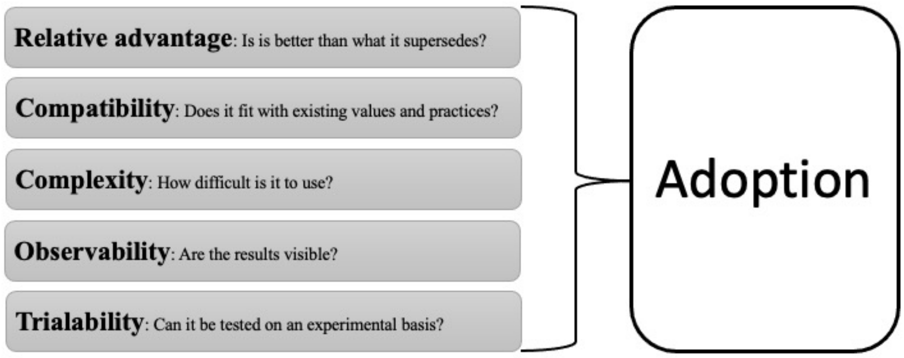
Diffusion refers to the communication of innovation at the social system level (Rogers, 2003). Within the social system (e.g., the U.S. Green Industry), people belong to one of five adopter categories relative to the specific innovation (Rogers, 2003). Innovators are among the first 2.5% to adopt an innovation, and they are followed by the early adopters (the next 13.5%). Next the early and late majority (34% and 34%, respectively) follow. Lastly, the laggards (the final 5%) may adopt the innovation. As adoption advances within a social system, it reaches a point of critical mass, at which point the diffusion of the innovation will be self-sustaining (Rogers, 2003). Importantly, someone may be very innovative regarding some types of innovation while being very resistant to change for others (Rogers, 2003). For example, a grower who is consistently among the first to plant new cultivars of hydrangea developed by their Land-Grant university may never adopt a complex point of sale system for their operation. For this reason, it is advantageous for Extension professionals to conduct regular audience research to understand adoption behaviors as they pertain to the specific innovation and audience.

At the individual level, there are five stages in the innovation-decision process (Rogers, 2003), and these can be used to understand growers' path to adoption. First, growers must become aware of an innovation and how it works (knowledge stage). Next, a grower forms their opinion about the innovation (persuasion stage), and this opinion can be described in terms of perceived relative advantage, compatibility, complexity, observability, and trialability (Rogers, 2003). These perceptions are described in further detail below and would support a grower's decision to adopt or reject an innovation (decision stage). Finally, following a decision to adopt, the grower would put the technology into use in their operation (implementation stage) and later decide whether to continue or discontinue its use (confirmation stage).

Perceived characteristics of automated nursery technologies can explain adoption processes among growers, and these factors form the foundation for the current study. First, relative advantage is the extent to which an innovation is perceived as being better than the technology or idea it supersedes. Relative advantage can be reflected in increased firm efficiency and reduced labor dependence offered by automated nursery technologies (Caplan et al., 2014). For example, technologies that transport the crop to the staff rather than requiring staff to travel through the entire production facility for maintenance tasks would improve efficiency while reducing labor needs (Giacomelli et al., 2008). Second, compatibility is the extent to which an innovation aligns with a grower's existing values and needs. For example, technologies should be adapted to local conditions, including governmental regulations and local climate (Giacomelli et al., 2008). Interestingly, the lack of labor available to learn about and install innovations has been shown to negatively affect the adoption of new technologies (Prokopy et al., 2019). In other words, although automated nursery technologies may help address existing labor shortages they could be seen as incompatible if firms do not have the manpower available to integrate them.

Complexity refers to how simple or difficult an innovation will be to use or understand. In our context, complexity is interesting because, in general, automated technologies require lower levels of ability to operate, but higher levels of skill for troubleshooting when they are not working correctly (Attewell, 1992). In addition, perceptions of complexity may be more significant when there are concerns over repairs and long-term maintenance of new technologies (Caplan et al., 2014). Observability refers to the degree of visibility of the results of an innovation. For example, in an environmental context, an innovation with a more obvious benefit to water quality might be more readily adopted than one whose benefits were less apparent (McCann et al., 2015). Lastly, trialability is the extent to which an innovation can be tested on an experimental basis. According to Rogers (2003), when people perceive innovations as having high relative advantage, compatibility, observability, and trialability, and low complexity, they are more likely to adopt (see Figure 1). Thus, if growers positively perceive these traits, they will be more likely to adopt automated nursery technologies.

Figure 1. *A model of the relationship between the five characteristics of innovation and adoption.*



Importantly, diffusion processes and the factors that influence them differ drastically across sectors and innovations (Fichter & Clausen, 2021). Caplan et al. (2014) used qualitative interviews to examine how communication channels and technology characteristics influence both specialty crop and nursery growers' adoption decisions. The authors hinted at several DOI characteristics in their findings. For example, interview participants who did not feel their operations spent much labor on checking insect traps were less inclined to adopt electronic insect trap barriers (Caplan, 2014), suggesting they perceived minimal relative advantage of the innovation. Similarly, nursery growers were provided with trapping materials and an intensive two-day training addressing the relative advantage, complexity, and compatibility of using several nonelectronic passive insect trapping mechanisms to prevent insect infestation (LeBude et al., 2017). Most participating growers stated they intended to adopt trapping systems after the workshop. However, three years later, most did not confirm continued use of the materials after initial implementation, highlighting the need to understand how to better support adoption in this sector (LeBude et al., 2017). Growers did, however, state they spent more labor deliberately scouting for pests using a standardized sampling plan in the actual target crops. This finding might indicate that the high complexity of monitoring pest emergence using traps and transferring that information to predict infestation served as a barrier to adoption of this technology and overall, the relative advantage was lower compared to current behaviors (e.g., simply waiting for insects to infest the crops a few weeks after emergence and then deciding to intervene).

A study of nursery and greenhouse growers' technology adoption demonstrated relative advantage, trialability, and observability play a role in implementation of water conservation technologies (Warner et al., 2020). In another study, also with nursery and greenhouse growers, Lamm et al. (2019) found relative advantage, complexity, and trialability were predictors of choices to implement water treatment technologies. Overall, there is minimal research examining adoption among nursery and greenhouse growers, and most of the published studies with this audience are in an environmental setting (e.g., water conservation). Warner et al. (2020) noted a dearth of quantitative research on adoption processes among growers. The two recent studies noted here have begun to fill this gap, but there has not yet been a quantitative investigation of growers' adoption of automated nursery technologies.

Purpose and Objectives

This work was part of a larger multi-institutional project evaluating the perceptions and needs of the U.S. Green Industry pertaining to labor and automation. The purpose was to evaluate how nursery growers' perceptions of automated nursery technologies relate to their adoption. The specific objectives were to: 1) illustrate growers' perceptions as they related to automated nursery technologies (relative advantage, compatibility, complexity, observability, trialability); 2) determine the relationship between the five characteristics of innovations and the current adoption of automated nursery technologies; and 3) examine the relationship between the five characteristics of innovations and the likelihood of adoption of automated nursery technologies.

Methods

A mixed-mode (online and paper) survey method was appropriate to achieve the objectives of this quantitative study (Dillman et al., 2009). A mixed-mode survey approach can result in a more representative sample and a more desirable response rate (compared to a unimodal design; Newberry & Israel, 2017). In addition, we used nonprobability sampling, which has become common and is considered appropriate for this type of exploratory study in agricultural education research (Lamm & Lamm, 2019; Vaske, 2008). Finally, before we conducted the study, our research protocol was approved by our respective institutional review boards.

Sample and Data Collection

The target population was U.S. nursery growers who have decision-making responsibility for the operation and who are 18 and older. We accessed the sample through nursery certificates in Tennessee, Oregon Association of Nurseries membership rosters, International Plant Propagators' Society (IPPS) membership rosters, and membership of the Florida Nursery, Growers, and Landscape Association. We used mixed-mode survey techniques, issuing email invitations to an online survey coded in Qualtrics and mailing print surveys to non-respondents and sample members for whom we had no email address. We issued an email invitation and a reminder email invitation to sample members for whom we had email addresses. To sample members for whom we had USPS addresses, we subsequently sent survey packets via USPS first class mail. For sample members for whom we had no email address, we sent two survey packets by USPS mail. The maximum number of contacts with any potential respondent was three. Altogether, the sample included 1,225 members in total, including 1,181 with a valid USPS address and 1,017 with a valid email address. We also promoted the survey to nursery growers through *Nursery Management* magazine, various Extension specialists across the US, and the project team website.

A screening question was used in the electronic version of the survey to verify that the respondent was in a decision-making capacity. On the paper version of the survey, instructions in the first screener question asked non-decision makers to forward the paper survey to an owner or manager within the company. Thus, respondents primarily consisted of higher-level leadership, including owners, presidents, CEOs, and other managers. Screening questions specifically targeted individuals familiar with the firms' operations and their ability to make decisions about the future direction of their firms. An additional screening question addressed the type of firm potential participants represented. Specifically, nursery production systems were targeted rather than retailers, greenhouse operations, landscapers, and other Green Industry sectors. Nurseries were of interest given the increased labor requirements for producing nursery stock (Astill et al., 2020; Mathers et al., 2010).

We received 98 completed paper surveys and 56 surveys completed online in response to our email invitations. Another 35 surveys were completed online by nursery owners or managers who responded to the magazine, Extension, and website promotion of the survey. Altogether we collected 189 completed responses. We used the type 1 completion and cooperation rate calculators of the American Association of Public Opinion Research (AAPOR, 2020). The type 1 calculator is the most conservative available. It does not remove any non-contact sample members from the denominator of the calculation, nor does it credit partial completions in the numerator of the calculation. In AAPOR response and cooperation calculations in which we do not include the 35 completed surveys that resulted from our general promotion efforts, the response rate is 11.8% and the cooperation rate is 89.0%. The response rate including these 35 additional completed surveys is 14.1% and the cooperation rate is 90.9%.

Survey content will be discussed after describing average firm characteristics (see Tables 1 and 2). The majority of represented firms were relatively new with nearly 37% of the sample being established after 2001 and 39% having an establishment date between 1976 and 2000. The mean year of establishment was 1982. Respondents averaged 57 years old and had been in decision making positions for 23 years. Respondents reported their firms' annual sales at $10.7 million. The majority of responding firms were in the Southeast U.S. followed by the Pacific region. Respondents also indicated their firms' succession plans. Not surprisingly, the largest proportion of the sample (44.7%) planned on a family member/inheritance to take over the business. Interestingly, 23.6% did not have a succession plan while 15% preferred not to disclose their plans.

Table 1

*Respondent and Firm Summary Statistics (*n *= 189)*

Variable Name	Definition	Mean
Role		
Owner, CEO, President	Participant is the owner, CEO, or president.	74.6%
Operations Manager	Participant is the operations manager.	14.3%
Production or Project Manager	Participant is the production or project manager.	6.9%
Other Employee (decision maker)	Participant is another employee with decision making responsibilities.	4.2%
Year of Establishment	Mean year of establishment of the firm.	1982
Before 1900	Established before 1900.	0.5%
1901 – 1925	Established between 1901 - 1925.	3.2%
1926 – 1950	Established between 1926 - 1950.	5.8%
1951 – 1975	Established between 1951 - 1975.	15.3%
1976 – 2000	Established between 1976 - 2000.	38.6%
2001 or later	Established during or after 2001.	36.5%
Years - Decision Maker	Mean years of being a decision maker at the firm.	22.7
Age	Mean age of participant.	56.76
Annual Sales		

Reported Annual Sales	Mean reported annual sales by participating firms.	$10,700,000.00
Location		
Zip0	Firm location in zip code region 0, including: CT, MA, ME, NH, NJ, RI, and VT.	2.7%
Zip1	Firm location in zip code region 1, including: DE, NY, PA.	2.7%
Zip2	Firm location in zip code region 2, including: DC, MD, NC, SC, VA, WV.	9.0%
Zip3	Firm location in zip code region 3, including: AL, FL, GA, MS, TN.	41.8%
Zip4	Firm location in zip code region 4, including: IN, KY, MI, OH.	5.8%
Zip5	Firm location in zip code region 5, including: IA, MN, MT, ND, SD, WI.	0.5%
Zip6	Firm location in zip code region 6, including: IL, KS, MO, NE.	2.1%
Zip7	Firm location in zip code region 7, including: AR, LA, OK, TX.	3.2%
Zip8	Firm location in zip code region 8, including: AZ, CO, ID, NM, NV, UT, WY.	0.5%
Zip9	Firm location in zip code region 9, including: AK, CA, HI, OR, WA.	12.2%
Succession Plans		
Family member/inheritance	Percent of surveyed firms planning on using this type of succession plan.	44.7%
Co-owner buy-out	Percent of surveyed firms planning on using this type of succession plan.	2.5%
Sell out short-term	Percent of surveyed firms planning on using this type of succession plan.	3.7%
Sell out long-term	Percent of surveyed firms planning on using this type of succession plan.	5.6%
Employee purchase	Percent of surveyed firms planning on using this type of succession plan.	3.1%
Rent-to-own	Percent of surveyed firms planning on using this type of succession plan.	0.6%
Acquisition from another firm	Percent of surveyed firms planning on using this type of succession plan.	1.2%
Do not have a succession plan	Percent of surveyed firms that do not have a succession plan.	23.6%
Prefer not to disclose	Percent of surveyed firms preferring to not disclose their succession plans.	14.9%

The represented businesses reflected the diversity often found in the Green Industry (Table 2). Many of the firms included a mix of production methods, with the majority (79%) having container-grown nursery plants, followed by field-grown nursery plants (53%), greenhouse operations (44%), retail components (20%), landscape services (12%), or other components (7%). The firms also grew a variety of different types of plants with propagated materials dominating the container-grown nursery operations. Deciduous shrubs, deciduous trees, evergreen shrubs, and herbaceous perennials, and grasses were also fairly popular. Among field-grown nurseries, trees (deciduous and evergreen) were the most grown items. The popularity of trees in field-grown operations is fairly intuitive given the space required to grow trees to saleable size. Mixed operations produced propagated materials, deciduous trees and shrubs, evergreen trees and shrubs, and herbaceous perennials and grasses. Given that these operations include a variety of production methods, the diversity of crops grown is not surprising.

Table 2

Production Characteristics and Plant Types Grown by Participating Firms

Variable	Definition	% of Sample		
Nursery: container-grown[a]	Business includes container-grown nursery	78.8%		
Nursery: field-grown[a]	Business includes field-grown nursery	53.4%		
Greenhouse[a]	Business includes greenhouse	44.4%		
Retail nursery/garden center[a]	Business includes retail nursery/garden center	19.6%		
Landscaping services[a]	Business includes landscaping service component	12.2%		
Other[a]	Business includes "other" component.	7.4%		
Nursery: container-grown	% total wholesale inventory in container-grown nursery	57.9%		
Nursery: field-grown	% total wholesale inventory in field-grown nursery	37.6%		
Plant Types Grown	Business includes different types of plants, by container vs. field production firms.	Container (n = 90)	Field (n = 47)	Mixed (n = 52)
Propagated materials[a]	Business grows propagated materials	89.8%	45.6%	83.3%
Deciduous trees[a]	Business grows deciduous shade, flowering, or fruit trees	72.7%	78.3%	81.3%
Deciduous shrubs[a]	Business grows deciduous shrubs	71.6%	47.8%	72.9%
Evergreen shrubs[a]	Business grows evergreen shrubs	68.2%	47.8%	72.9%
Evergreen trees[a]	Business grows evergreen trees	58.0%	58.7%	66.7%
Palms[a]	Business grows palms	20.7%	2.2%	12.5%
Vines and ground covers[a]	Business grows vines and ground covers	55.7%	2.2%	43.8%
Herbaceous perennials and grasses[a]	Business grows herbaceous perennials and grasses	70.5%	2.2%	62.5%
Foliage[a]	Business grows foliage plants	21.8%	2.2%	20.8%

[a] 1 = yes; 0 = no.

Instrumentation

The instrument was a researcher-developed survey. Eight questions addressed the study objectives. The variables were the DOI perceptions of innovations (relative advantage, compatibility, complexity, observability, and trialability; Rogers, 2003), current adoption of automated nursery technologies, and the likelihood of adopting automated nursery technologies.

A series of four- to six-item Likert-type scales measured the five DOI characteristics. Participants were instructed to *please indicate your level of disagreement or agreement with the following statements as they pertain to adopting automated nursery technologies* for each item. These scales were adapted from three existing DOI instruments (Moore & Benbasat, 1991; Warner et al., 2020; Zolait & Sulaiman, 2008). The scales were modified with thematic findings drawn from listening sessions conducted with nursery and greenhouse growers as an earlier part of the larger project. Reliability was estimated using Cronbach's alpha and exceeded

.70 for all indexes (see Table 3), indicating they were suitable for use (Cronbach, 1951; Vaske, 2008).

Table 3

Description of Independent Variables in an Evaluation of the Relationship between U.S. Nursery Growers' Perceptions and Adoption of Automated Nursery Technologies

Question stem and individual items	Cronbach's alpha[a]
Relative advantage index	
Automated nursery technologies…	.807
... can help my operation perform tasks better than in the past.	
... could be a solution to labor issues.	
... will increase my operation's costs.[b]	
... will improve the quality of the products we produce.	
... could improve my return on investment.	
... would be appreciated by my customers.	
Compatibility index	
Automated nursery technologies are compatible with my operation.	.831
Employees within my operation will accept automated nursery technologies.	
There is adequate maintenance support for automated nursery technologies.	
Automated nursery technologies would be easy to integrate into my operation.	
There would be management buy-in for automated nursery technologies within my operation.	
Automated nursery technologies can be adapted to fit my needs.	
Complexity index	
Learning to use automated nursery technologies would be easy for employees at my nursery.	.819
It would be easy for my employees to become skillful at using automated nursery technologies.	
Automated nursery technologies are straightforward.	
There is enough technical support for automated nursery technologies.	
Observability index	
I would use automated nursery technologies if I saw other growers having good results.	.796
If the industry was positively reviewing automated nursery technologies, I would be more likely to try them.	
I will use automated nursery technologies when a lot of other people do.	
I would use automated nursery technologies if I could see them in use.	
The results of using automated nursery technologies are apparent to me.	
I have the opportunity to see real life examples of automated nursery technologies.	
Trialability index	
Automated nursery technologies are available to try out before I make a decision about using them.	.845
I usually have the opportunity to test automated nursery technologies before I commit to changing part of my operation.	
I usually do not have the chance to try automated nursery technologies.[b]	
I can usually use automated nursery technologies on a trial basis.	
I am able to experiment with automated nursery technologies as needed.	

Note. All question formats were Likert-type scales. Possible responses and values were *strongly disagree* (-2), *disagree* (-2), *neither disagree nor agree* (0), *agree* (1), and *strongly agree* (2). [a]*Post-hoc* reliability reported. [b]Indicates reverse-coded responses which were reverted prior to data analysis.

The outcome variables were the current use of a suite of automated nursery technologies and the likelihood of adoption of automated nursery technologies. The list of automated nursery technologies was researcher-generated with edits and additions provided by an 11-member team of nursery and horticultural production experts from six institutions. To ensure consistent interpretation, respondents were informed that *"automated nursery technologies" refers to both automation (sensor-based) and mechanization (gear-based mechanical advantage)*. There were 27 technologies in total. However, the number that applied to the respondent varied by whether they were predominantly field growers, container growers, or grew a mix of the two.

Field growers were defined as those who indicated 76%-100% of the plants in their 2020 wholesale inventory were field grown. Container growers were defined as those who indicated 76%-100% of the plants in their 2020 wholesale inventory were container grown. Mixed growers employed a variety of production methods (including container and field grown). Mixed growers were defined as those who grew 75% or less of their 2020 wholesale inventory using field or container methods. There were 23, 18, or 27 technologies applicable to field, container, or mixed growers, respectively. On the paper survey, the technologies were clearly delineated using instructions and visual separations while the electronic survey was programmed so only the applicable technologies were shown to participants.

For each applicable technology, a respondent could indicate if they were *currently using it*, or they could indicate their likelihood of adoption on a scale from *very unlikely* (-2) to *very likely* (2). To standardize the responses, current use was coded with a 1 and the absence of current use was coded with a 0, and a mean value was calculated within all responses applicable to the grower type (field, container, mixed). Likelihood of adoption was calculated as the mean of all likelihood responses for the technologies applicable to the particular grower among those they did not indicate they already used.

Before data collection, we conducted a 5-member expert panel review to improve accuracy and establish content and face validity (Vaske, 2008). The expert panel included individuals with expertise in nursery Extension education and nursery crops production.

Data Analysis

All data analyses were conducted using SPSS (version 26.2; IBM Corp., Armonk, NY). Objective One was achieved using descriptive statistics to generate means and standard deviations for the dependent and independent variables. Objectives Two and Three were achieved using multiple linear regression to examine how the five DOI characteristics related to adoption of automated nursery technologies. Before proceeding with the regression analyses, we examined the data and confirmed it met all assumptions (normality, linearity, absence of multicollinearity, and homoscedasticity).

Findings

Objective One: Describe growers' perceptions as they related to automated nursery technologies (relative advantage, compatibility, complexity, observability, trialability).

The current adoption index indicates responding growers were using 25% of the technologies applicable to their operation (see Table 4). Container growers tended to be most engaged with using automated nursery technologies. Respondents indicated their overall likelihood of adoption was neutral but slightly negative, indicating weak overall likelihood of adoption.

Table 4

Description of Dependent Variables in an Evaluation of the Relationship between U.S. Nursery Growers' Perceptions and Adoption of Automated Nursery Technologies

	M	*SD*
Current Use of Automated Nursery Technologies (range = 0 to 1)[a]		
Field	.218	.186
Container	.406	.264
Mixed	.133	.202
Overall	.251	.255
Likelihood of Adoption of Automated Nursery Technologies (range = -2 to +2)[a]		
Field	-.227	.890
Container	.022	1.050
Mixed	-.211	.895
Overall	-.094	.979

Note. There were 27 automated technology items. 23 applied to field growers, 18 applied to container growers, and 27 applied to mix growers. [a]Question format was check all that apply. Current use items were mutually exclusive meaning that when a respondent indicated they used a specific technology they could not also indicate likelihood of adoption. [b]Question format was a Likert-type scale. Possible responses and values were *very unlikely* (-2), *unlikely* (-1), *neither unlikely nor likely* (0), *likely* (1), and *very likely* (2).

Growers had relatively strong perceptions of observability and relative advantage. As indicated by mean values approaching 1, respondents tended to agree with the individual items within these indexes, on average (see Table 5). Compatibility, complexity, and trialability were lower, and with mean values closer to 0, respondents tended to feel more neutral toward the individual items on average within these indexes.

Table 5

Descriptive Statistics in an Evaluation of the Relationship between U.S. Nursery Growers' Perceptions and Adoption of Automated Nursery Technologies

Variable	*M*	*SD*
DOI Characteristics		
Observability	.622	.650
Relative advantage	.621	.680
Compatibility	.418	.691
Complexity	.098	.678
Trialability	-.425	.743
Current adoption index	.251	.255
Likelihood of adoption index	-.094	.979

Note. DOI characteristics and likelihood of adoption indexes could range from -2 to 2. Current adoption index could range from 0 to 1.

Objective Two: Examine the relationship between the five characteristics of innovations and current adoption of automated nursery technologies.

The regression model using DOI characteristics to predict current adoption was significant, $F(5,159) = 9.726$, $p < .001$, and predicted about 23% of the variance in adoption (see Table 6). Compatibility had the strongest predictive relationship with current adoption, followed by trialability, and then complexity. The relationship between compatibility and adoption was positive, while complexity and trialability both related negatively to adoption. Neither relative advantage nor observability predicted current adoption.

Table 6

DOI Characteristics Predicting Current Adoption of Automated Nursery Technologies in an Evaluation of the Relationship between U.S. Nursery Growers' Perceptions and Adoption of Automated Nursery Technologies

	AIC	R^2	*B*	*β*	*p*
Overall model*	-506.987	.234			< .001
Relative advantage			.020	.058	.558
Complexity*			-.060	-.171	.038
Compatibility*			.102	.293	.009
Observability			.074	.196	.060
Trialability*			-.066	-.206	.005

Note. * indicates significant. *B* are unstandardized regression coefficients and *β* are standardized regression coefficients. AIC is the Akaike Information Criterion.

Objective Three: Examine the relationship between the five characteristics of innovations and likelihood of adoption of automated nursery technologies.

The regression model using DOI characteristics to predict the likelihood of adoption was significant, $F(5,145) = 9.006$, $p < .001$, and predicted about 24% of the variance in the likelihood of adoption (see Table 7). Beta values revealed compatibility had the strongest relationship with likelihood of adoption, followed by relative advantage, and then complexity. These relationships were positive, excluding complexity, indicating greater perceptions of compatibility and relative advantage along with lower perceived complexity related to the greater likelihood of adoption. There was no significant relationship between either trialability or observability and the likelihood of adoption.

Table 7

DOI Characteristics Predicting Likelihood of Adoption of Automated Nursery Technologies in an Evaluation of the Relationship between U.S. Nursery Growers' Perceptions and Adoption of Automated Nursery Technologies

	AIC	R^2	*B*	*β*	*p*
Overall model*	-39.156	.237			< .001
Relative advantage*			.322	.219	.030
Complexity*			-.259	-.181	.035
Compatibility*			.378	.263	.022
Observability			.201	.126	.228
Trialability			.123	.091	.225

Note. * indicates significant. *B* are unstandardized regression coefficients and *β* are standardized regression coefficients. AIC is the Akaike Information Criterion.

Conclusions and Implications

This study was conducted to describe growers' perceptions of automated nursery technologies and to examine how these perceptions related to their current use of and likelihood of adopting these innovations. Responding growers were using about one out of four of the technologies they were asked to evaluate, and their overall likelihood of adoption was slightly negative but neutral. The response was possibly diluted since this measure considered all technologies relevant to their grower type (field, container, mixed). However, this finding makes sense given the number of automation technologies they were asked to evaluate. Likely growers would not want to adopt many technologies simultaneously, given the capital investment and the potential disruptions that would be needed to make many changes all at once. Rather, growers would likely prefer to adopt one new technology at a time to space out resource requirements and potential risks.

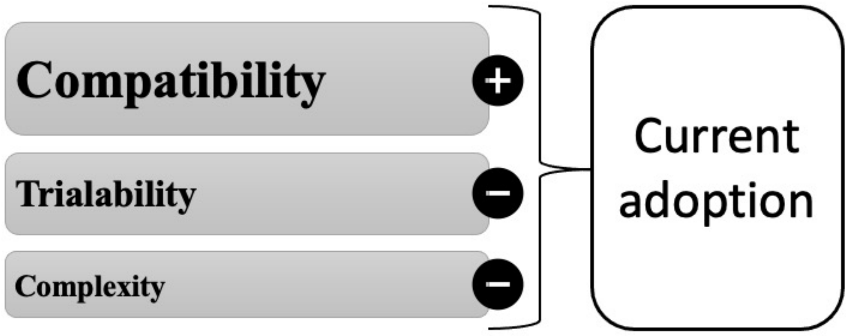
Perceptions of observability and relative advantage were somewhat high, meaning growers can see the results of using automated nursery technologies and also believe they are better than technologies or ideas they supersede. Compatibility was also positive, indicating growers believe automated nursery technologies fit with their existing firms, infrastructure, and values. The favorable perceptions of observability, relative advantage, and compatibility hint at general buy-in for these types of innovations and should support adoption of automated nursery technologies. Complexity was notably perceived as being neutral, indicating these innovations are not viewed as particularly difficult to use, and this characteristic should not be a barrier to adoption of automated nursery technologies. Trialability was the most weakly viewed perception and was also negative, meaning growers do not perceive they have the ability to test automated nursery technologies before committing to adopting them. Following DOI, the lack of perceived trialability could present a barrier to adoption.

The strong perceptions of relative advantage are not particularly surprising, and this implies growers believe automated nursery technologies will improve upon technologies and practices used currently and in the past. Interestingly, perceptions of observability were high. This finding, paired with strong perceptions of relative advantage, implies the possible presence of a robust social norm valuing these types of technologies within this industry. For example, growers may be sharing their positive results with other growers. They may also have the opportunity to see these innovations at other growers' operations, field days, and trade shows. Perhaps, in the absence of the ability to try out the technology (indicated by low perceived trialability), many growers are viewing their peers' experiences and then adopting if the technology appears to be working and improving efficiency.

The positive perception of compatibility indicates perceptions of automated nursery technologies differ from that of other types of innovations developed for this industry. For example, Lamm et al. (2017) reported a lack of compatibility (e.g., with existing nursery or greenhouse structures, with views of horticulture as a hands-on industry) when considering innovations related to water treatment. Thus, one might expect that automated nursery technologies would also be viewed as incompatible for these reasons; however, our findings implied otherwise.

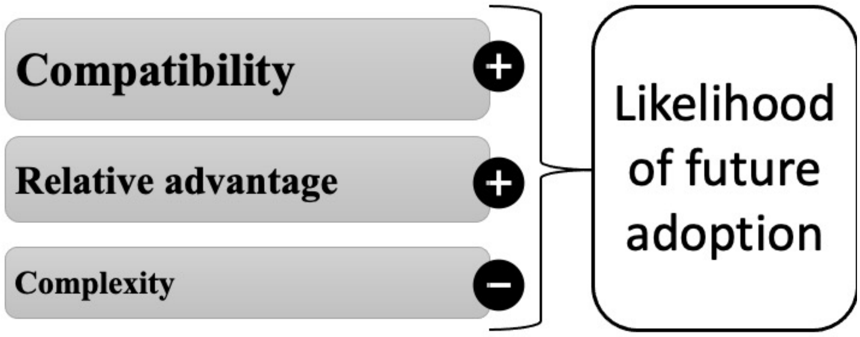
When the five characteristics were considered together, compatibility, trialability, and complexity predict nursery growers' current adoption of automated nursery technologies (see Figure 2). However, it is interesting to note the inverse relationship between perceptions of trialability and adoption, despite overall low perceptions of trialability itself. It may be possible growers who do perceive they can try out these technologies have not had good trial experiences and are therefore less likely to adopt. Further, since they have not fully committed, they have not had the whole experience of using the technologies and integrating them into their own production systems.

Figure 2. *A model of the relationship between the five characteristics of an innovation and current adoption of automated nursery technologies*



Compatibility, relative advantage, and complexity predict the likelihood of adopting these innovations in the future (see Figure 3). Compatibility had the largest effect size in both models.

Figure 3. *A model of the relationship between the five characteristics of an innovation and likelihood of future adoption of automated nursery technologies.*



The current study's findings do not align with similar studies of nursery growers' adoption. For example, compatibility was the most important predictor of current and future adoption of automated nursery technologies. However, this characteristic was not a predictor of U.S. nursery growers' use of either water conservation (Warner et al., 2020) or water treatment (Lamm et al., 2019) technologies. These two studies reported relative advantage was the highest predictor of use for these two types of innovations (Lamm et al., 2019; Warner et al., 2020). Yet, this characteristic was not a significant predictor of current or future adoption of automated nursery technologies in the present study. However, in a mixed methods multi-sector study of the diffusion of 130 environmental diffusion cases, compatibility was an essential and consistent predictor of energy-efficient and agriculture-related innovation adoption (Fichter & Clausen, 2021). These differences underscore the need to conduct behavior-specific research with the target audience to better understand their drivers of adoption and encourage the use of sustainable production technologies and practices.

Recommendations

There is a need to provide education for different levels of the labor force (Giacomelli et al., 2008), and university researchers and Extension professionals are among the top sources of information for agricultural professionals (King & Rollins, 1995). Extension plays a critical role in disseminating new ideas throughout the agricultural industry via their relationships with stakeholders. For example, farmers who adopted a specific fertilization technique reported higher opinions of Extension professionals than non-adopters (King & Rollins, 1995). Given that awareness and positive perceptions of innovations must precede adoption (Rogers, 2003), providing this evaluative information within local social systems plays a vital role for Extension professionals and other practitioners (Caplan et al., 2014).

The current study generated clear opportunities to influence and accelerate the adoption of automated nursery technologies. Since compatibility and complexity are predictors of both current and future adoption, researchers and Extension professionals should emphasize these two areas in both the development and diffusion of automated nursery technologies. Because compatibility was the most critical factor for both current adoption and future likelihood of adoption, above all else, researchers designing automated technologies need to ensure innovations fit with growers' existing infrastructure and values. Extension professionals can support growers by helping them identify technologies that fit with their existing infrastructures and provide information to aid in understanding how technology can be adapted to existing operations. In addition, educational materials should emphasize how these technologies support more meaningful hands-on horticultural activities rather than removing the manual nature of growing plants.

To reduce potential perceptions of complexity, growers need access to training and instructional materials that simplify the integration, use, and maintenance of automated technologies. As relative advantage is also an essential component for future adoption, resources that provide detailed quantification of the relative advantage including the economic advantage may be vital in building momentum for the diffusion of automated nursery technologies. When growers perceive these innovations are better than past practices or previously adopted technologies, their perceptions of relative advantage will be positively impacted.

Overall, growers do not perceive they can see the results of automated technologies or try them out on a trial basis. One aspect of innovators adopting technologies before peers in their surrounding area might be the ability to purchase equipment before others. This practice could result in incompatible purchases because there is no trialability before purchase. These growers may be seen as "wasting money on new toys or the latest gadget" and paying to fail. However, they might be insensitive to failure, may not perceive failure as a negative, or at the very least are trying to fail as quickly as possible to determine the most successful innovations for their operations. One difference between innovators and later adopters is a higher level of risk tolerance (Rogers, 2003). In practice, the difference might not be capital income to invest in automation but different perceptions of failure as a path to improve production. The acceptable level of risk is much lower with later adopters (Rogers, 2003), so they wait until they have examples of success among their peers, perceive sufficient compatibility with their systems, or they become familiar enough with the technology that they can imagine it working in their system. This perspective is an excellent opportunity for Extension to act as a catalyst in technology adoption.

Extension professionals working with automation providers and early adopters, as well as others who support this industry, could leverage these factors to make technology more readily observable and trialable thus reducing growers' perceived risk of adoption. However, these experiences must be positive for growers. One possibility is to have Extension production fields serve as demonstrations of technology in use throughout the growing season to provide real-time examples of the technologies at work. Given the inclusiveness of Extension programs, growers could be allowed to interact with the new automation technologies at the field stations to better understand their potential. Recommendations could be developed based on clientele operations' specifics. Many Extension professionals currently offer hands-on demonstrations of techniques, such as the Virginia Tech Extraction Method, and field days with plant variety trials, and pesticide efficacy trials. However, the importance of doing so cannot be overemphasized especially when considering expensive, new innovations that can aid in production and sustainability initiatives. Educational videos from the user's perspective while operating various pieces of automation could also be produced through the Cooperative Extension Service to provide a controlled trialability experience for nursery producers.

Given that we could not include all potential respondents in the sampling frame, there are limitations to the study, and the reader should use their judgement concerning the results (Lamm & Lamm, 2019). There was a disproportionate number of responses from growers in the southeastern region of the U.S. We have partially mitigated coverage bias through the use of a mixed-mode survey, allowing for a larger proportion of the potential audience to participate. Future research in this area should consider random sampling, weighting measures, or quota sampling to further control for error (Lamm & Lamm, 2019).

We offer several potential future directions for researchers to consider. First, we concur with previous recommendations that more research (Caplan et al., 2014) and specifically more quantitative studies (Lamm et al., 2017; Warner et al., 2020) need to be conducted to better understand adoption processes within this vital industry. Second, we approached this study looking at several innovations collectively, a concept which Rogers (2003) described as "technology clusters" (p. 249). We used a suite of innovations given that the adoption of an innovation can promote the adoption of complementary behaviors (Rogers, 2003). Including all the technology options as we did here may have diluted the overall likelihood of adoption, which could have masked the true strength of existing relationships. Targeted behavior change interventions will be most effective when they are informed by audience research on the specific audience and specific behavior (McKenzie-Mohr, 2011), and we recommend future replications but with constructs aligned with specific individual technologies to provide the best possible insights for promoting adoption. Alternatively, researchers building on this work might consider grouping the innovations by technology type (e.g., irrigation, plant transport, pruning, potting/mixing, etc.).

Our study examined the relationship between theory based DOI characteristics and adoption, but it is well known that contextual variables (e.g., formal education, age, geographical location, etc.; Prokopy et al., 2019) can increase the understanding of growers' adoption behaviors. Future research should also explore social norms surrounding the use of automated technologies. While it was outside the scope of the current study to compare differing influences on current use and the likelihood of adoption, there were distinctions, and future research may examine whether this finding is valuable in understanding growers' adoption processes. Further, research has shown that engaging in similar practices is related to adopting new practices (Prokopy et al., 2019), and such relationships should be explored in future work.

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