Ornamental Grower Perceptions of Wireless Irrigation Sensor Networks: Results from a National Survey

John Majsztrik1,3, Erik Lichtenberg2, and Monica Saavoss2

Additional Index Words. precision irrigation, sensor technology, technology adoption, wireless sensor networks

Summary. Irrigation management systems that use wireless transmission of substrate moisture data are beginning to become commercially available for ornamental growers, particularly for use in soilless substrates. These systems allow growers to precisely monitor and control irrigation in real time and are being shown to save time and other resources. On-farm evaluations indicate that these systems have potential benefits extending beyond reductions in water use and associated irrigation inputs: Some growing systems experience increases in plant growth rates, with corresponding reductions in production time, whereas some experience reductions in disease pressure and corresponding plant losses. We asked ornamental growers across the nation what they see as potential benefits and limitations of these systems as a means of assessing the likely state of acceptance of this technology at the time of its initial introduction. Grower perceptions were overwhelmingly positive, with the majority of respondents agreeing that wireless sensor systems can increase irrigation efficiency, improve product quality, reduce product losses, reduce irrigation management costs, reduce disease prevalence, increase ability to manage growth, reduce irrigation management costs, and reduce monitoring costs. System cost and reliability were major concerns. Grower perceptions of the benefits and drawbacks of irrigation sensor networks varied across size and type of operation as well as geographically and by the type of water source used. Making wireless sensor systems affordable and robust will likely be critical determinants of the speed and reach of adoption of these technologies.

Automation can improve irrigation efficiency, but automation needs both hardware and software to do so. Many soil-moisture-sensor-based systems use hardware to measure and track substrate moisture levels and specialized software to display data, interact with the sensor network and irrigation system, and help the grower determine how much moisture plants need at any given point in time. Complete automation packages that combine the requisite hardware and software with control capabilities are only just beginning to become available. Recent experiments using sensor-based irrigation technology have shown that irrigation decisions made using these control systems saved water and, in some cases, reduced disease losses and improved plant growth (Belayneh et al., 2013; Chappell et al., 2013; Nemali and van Iersel, 2006). Water-saving strategies are becoming more common in ornamental operations, and improvements in irrigation efficiency are likely to become increasingly important as rainfall patterns become increasingly unpredictable and competition with cities for limited freshwater resources promise to drive up the cost of water and limit its availability (Majsztrik et al., 2011). Reductions in shrinkage (plant death) and production time can increase profitability substantially by allowing growers to sell more plants with the same amount of production area in a given amount of time (Lichtenberg et al., 2013). Improvements in irrigation efficiency can also have important environmental benefits, some of which can translate into substantial cost savings as environmental regulations become more strict (Belayneh et al., 2013; Chappell et al., 2013; Majsztrik et al., 2013).

There are a number of companies currently offering different types of wireless sensor systems, each with its own strengths and limitations, including Toro (Azusa, CA), Freeland (Ottawa, ON, Canada), and UgMO (King of Prussia, PA). Decagon Devices (Pullman, WA) is the only commercial system we are aware of that can be used for irrigation control of container-grown ornamental plants. A coordinated multistate project using Decagon Devices components, funded in 2009, has advanced both hardware and software to the point where these systems can feasibly be implemented at ornamental operations, including a series of experiments on wireless sensor networks (Kohanbash et al., 2013; Lea-Cox, 2012; Lea-Cox and Belayneh, 2012; Lea-Cox et al., 2010, 2013). These experiments have used tests in research plots and ornamental growing operations to answer questions about sensor placement, accuracy, and robustness, while developing user-friendly hardware and software.

Advances achieved through these experiments have placed this technology on the threshold of commercialization; therefore, current perceptions are important determinants of initial acceptance and adoption by growers. To gain a better understanding of ornamental grower practices and perceptions, we conducted a national survey to collect information on a number of topics including current perceptions of wireless sensor systems. This article focuses on grower perceptions of a range of potential benefits that have been found in experimental and operational test systems as well as deterrents to adoption. We also examine the extent to which those perceptions

This paper is part of a series of manuscripts describing the research and development completed by the SCRI-MINDS (Managing Irrigation and Nutrition through Distributed Sensing) project. The authors gratefully acknowledge funding and support from the USDA-NIFA Specialty Crops Research Initiative; Award #2009-51181-08768.

The authors sincerely thank the extension specialists and grower organizations who helped distribute the survey links, and the growers for their time filling out the survey to make this research possible. The authors also appreciate the comments from the anonymous reviewers who helped improve this manuscript.

1Department of Plant Science and Landscape Architecture, 212SD Plant Sciences Building, University of Maryland, College Park, MD 20742
2Department of Agricultural and Resource Economics, 2102 Symons Hall, University of Maryland, College Park, MD 20742
3Corresponding author. E-mail: jcmajsz@umd.edu.
differ systematically according to operation size, financial status, and composition as it related to location and water sources in the United States.

Materials and methods

We developed and implemented a survey of greenhouse and nursery growers as part of a larger project focused on developing wireless sensor networks to reduce water use and improve crop health and productivity. The survey design made use of input from growers, industry experts, and experts in survey methodology. The survey itself was administered in two phases. The initial survey instrument, asked for detailed information about greenhouse, container, and field production, plus information on runoff collection and containment for each responding operation in addition to general site information, basic economic information, and perceptions of wireless sensor networks. The second phase used a shortened version of the original instrument that asked only for general site information, basic economic information, and perceptions of wireless sensor networks.

Both instruments were created and administered online using SurveyMonkey (Palo Alto, CA). Links to the survey were distributed through a variety of means including trade shows, through state Cooperative Extension specialists, state and regional nursery and landscape associations, and other listservs. The first phase of the survey was administered from Jan. through Dec. 2012. About midway through the survey (June 2012), a grand prize incentive of a sensor network valued at $5000 was donated by Decagon Devices. The second distribution phase of the shortened survey was administered from 15 Jan. to 31 Mar. 2013, with a drawing for an iPad (Apple, Cupertino, CA) offered as a participation incentive to growers for completing the entire survey.

Growers were asked about their views on potential advantages and limitations of wireless sensor networks (Table 1). The order in which all responses except “other” were presented was randomized to avoid response bias.

Probit models were used to analyze survey results. Probit models use a dependent variable, which has only two values (e.g., a yes or no question). The independent variables are the farmer attributes and can be continuous (such as production area) or discrete (such as region). The model then predicts the effect (change in probability) of the respondent answering yes based on each of those attributes. This type of model effectively controls for systematic differences in perceptions due to size and composition of operation, regional location, and water source by controlling for the effects of all observed attributes at once. Probit was chosen in preference to logit or other similar models.

| Water source (yes = 1) | 27.49 | 37.83 |
|------------------------|-------|-------|
| Municipal water (yes = 1) | 0.21 | 0.41 |
| Other water (yes = 1) | 0.10 | 0.30 |
| Region | | |
| Appalachian (yes = 1) | 0.19 | 0.40 |
| Midwest (yes = 1) | 0.10 | 0.29 |
| Northeast (yes = 1) | 0.20 | 0.40 |
| Pacific (yes = 1) | 0.24 | 0.43 |
| Southeast (yes = 1) | 0.18 | 0.39 |

Table 2. Descriptive statistics of data used in probit models. Responses were collected nationally from ornamental operations by online survey. Survey responses were collected from Jan. 2012 through March 2013.

Table 1. Survey questions regarding grower perceptions of wireless sensor networks.

| “As part of this project, we are developing and testing sensor networks that can monitor root zone moisture, weather, and many other variables for precision irrigation and nutrient management. These more advanced sensor networks can automatically turn irrigation on and off as needed, reducing or eliminating the need for manual irrigation control. The sensors decide when, where, and how much to irrigate based on set points you determine. Answering the questions below will help us to better understand the extent of technology adoption in the nursery and greenhouse industry.” |

| In what way do you think information from such a sensor network might impact your operation? (Control all that apply) | 1) Reduce product loss |
| 2) Reduce disease occurrence |
| 3) Increase efficiency of irrigation |
| 4) Reduce irrigation management cost |
| 5) Increase ability to manage crop growth rates |
| 6) Increase quality |
| 7) Reduce monitoring time/costs |
| 8) Other ______________________ |

| What would be your biggest concern(s) if you decided to begin using an irrigation sensor network that could monitor and control irrigation at your operation? (Control all that apply) | 1) There would be too much maintenance involved |
| 2) The cost would be too high |
| 3) The sensors would not be reliable |
| 4) The sensors would not control irrigation correctly |
| 5) The sensors would not be as efficient as our current system |
| 6) Other ______________________ |
specifications because the normal distribution is a good approximation for any distribution for sample sizes like ours.

In formal terms, the probability that grower \( j \) answered “yes” to question \( k \) about perceptions of wireless sensor networks was modeled as 
\[
P(y_{jk} = 1) = \Phi(X_j \beta_k)
\]
Here, \( \Phi \) denotes the cumulative standard normal distribution and \( y_{jk} \) takes on a value of 1 if the respondent answers affirmatively to question \( k \) and 0 otherwise. Grower attributes \( X \) include operation size in acres, annual revenue, composition (percent of revenue from container greenhouse and field operations), dummy variables for

| Variable | Reduce product Loss | Increase quality | Increase efficiency | Reduce disease loss | Reduce irrigation management costs | Increase ability to manage growth | Reduce monitoring costs |
|----------|---------------------|------------------|--------------------|--------------------|-----------------------------------|-------------------------------|------------------------|
| Annual sales (million $) | 0.0014 | 0.026 | 0.0013 | 0.028 | 0.0032 | 0.040* | -0.00014 |
| (yes = 1) | (0.69)* | (0.15) | (0.76) | (0.12) | (0.48) | (0.063) | (0.96) |
| Annual sales missing | -0.0047 | -0.15** | -0.023 | -0.019 | 0.019 | -0.061 | 0.072 |
| Size (acres)\(^1\) | 0.00015 | 0.000040 | -0.00012*** | 0.000055 | 0.000027 | 0.000027 | 0.000093 |
| (yes = 1) | (0.13) | (0.53) | (0.003) | (0.40) | (0.63) | (0.33) | (0.15) |
| Revenue from greenhouse operation (%) | -0.0013 | -0.0047*** | 0.00093 | 0.0087 | 0.0066 | 0.00066 | 0.0017 |
| (yes = 1) | (0.52) | (0.018) | (0.46) | (0.65) | (0.73) | (0.69) | (0.39) |
| Water source | | | | | | | |
| Shallow well (yes = 1) | 0.076 | -0.053 | 0.034 | 0.23*** | -0.18** | -0.017 | -0.23*** |
| (yes = 1) | (0.37) | (0.48) | (0.57) | (0.01) | (0.018) | (0.84) | (0.002) |
| Deep well (yes = 1) | 0.13 | 0.069 | 0.14** | 0.25*** | 0.092 | 0.090 | -0.019 |
| (yes = 1) | (0.10) | (0.33) | (0.016) | (0.00) | (0.20) | (0.24) | (0.80) |
| Surface water (yes = 1) | 0.11 | 0.025 | 0.076 | 0.17** | -0.022 | 0.027 | -0.13* |
| (yes = 1) | (0.16) | (0.73) | (0.20) | (0.027) | (0.76) | (0.72) | (0.088) |
| Recycled water (yes = 1) | 0.068 | 0.0084 | 0.041 | -0.011 | 0.15* | -0.02 | -0.0080 |
| (yes = 1) | (0.40) | (0.91) | (0.49) | (0.89) | (0.063) | (0.77) | (0.99) |
| Rain (yes = 1) | 0.094 | 0.0068 | 0.076 | -0.043 | 0.10 | -0.002 | 0.25*** |
| (yes = 1) | (0.26) | (0.93) | (0.24) | (0.60) | (0.22) | (0.98) | (0.002) |
| Municipal water (yes = 1) | 0.14 | 0.06 | -0.012 | 0.20** | 0.081 | 0.26*** | 0.027 |
| (yes = 1) | (0.15) | (0.51) | (0.86) | (0.045) | (0.38) | (0.008) | (0.78) |
| Other water (yes = 1) | 0.063 | -0.095 | 0.099 | 0.25** | 0.068 | 0.034 | 0.027 |
| (yes = 1) | (0.58) | (0.35) | (0.23) | (0.031) | (0.51) | (0.76) | (0.78) |
| Region | | | | | | | |
| Appalachian (yes = 1) | 0.23* | 0.17 | 0.12 | 0.28** | -0.15 | 0.37*** | -0.080 |
| (yes = 1) | (0.063) | (0.15) | (0.15) | (0.019) | (0.21) | (0.002) | (0.53) |
| Midwest (yes = 1) | 0.14 | 0.14 | 0.35* | 0.19 | -0.16 | 0.38*** | 0.0079 |
| (yes = 1) | (0.33) | (0.30) | (0.052) | (0.18) | (0.24) | (0.008) | (0.96) |
| Northeast (yes = 1) | 0.14 | -0.0044 | -0.016 | 0.12 | -0.26** | 0.21* | -0.15 |
| (yes = 1) | (0.25) | (0.97) | (0.83) | (0.30) | (0.032) | (0.077) | (0.25) |
| Pacific (yes = 1) | 0.13 | 0.063 | 0.14* | 0.13 | -0.072 | 0.35*** | -0.20* |
| (yes = 1) | (0.26) | (0.55) | (0.089) | (0.25) | (0.54) | (0.002) | (0.97) |
| Southeast (yes = 1) | 0.081 | 0.12 | -0.097 | 0.21* | -0.087 | 0.23* | -0.25** |
| (yes = 1) | (0.51) | (0.31) | (0.21) | (0.088) | (0.49) | (0.07) | (0.048) |
| Observations | 252 | 252 | 252 | 252 | 252 | 252 | 252 |
| Chi-square P \(^1\) | 0.143 | 0.011 | 0.001 | 0.003 | 0.001 | 0.001 | 0.003 |
| Pseudo \( R^2 \) | 0.076 | 0.117 | 0.209 | 0.118 | 0.126 | 0.130 | 0.114 |

\(^1\)Probability values are in parentheses.
\(^1\)1 acre = 0.4047 ha.
\(* P < 0.10, ** P < 0.05, *** P < 0.01.

Table 3. Marginal effects for questions about perceived advantages of wireless sensor systems. Marginal effects are based on probit models. Responses were collected nationally from ornamental operations by online survey. Survey responses were collected from Jan. 2012 through Mar. 2013.
Table 4. Marginal effects for questions about perceived limitations of wireless sensor systems. Responses were collected nationally from ornamental operations by online survey. Survey responses were collected from Jan. 2012 through Mar. 2013.

| Variable                                      | Cost too high | Would not control irrigation correctly | Not reliable | Too much maintenance | Not as efficient as current system |
|-----------------------------------------------|---------------|----------------------------------------|-------------|----------------------|----------------------------------|
| Annual sales (million $)                     | 0.010         | 0.00043                                | -0.00054    | 0.019**              | 0.003                            |
| Annual sales missing (yes = 1)               | (0.48)*       | (0.892)                                | (0.87)      | (0.022)              | (0.10)                           |
| Size (acres)*                                 | 0.000018      | -0.0000099                             | 0.000104    | -0.0000030           | 0.0000066                        |
| Revenue from greenhouse operation (%)        | -0.0023       | -0.0055                                | -0.00054    | -0.0013              | -0.0010                          |
| Revenue from container operation (%)         | -0.00057      | 0.0012                                 | 0.0007      | 0.00033              | -0.0020*                         |
| Revenue from field operation (%)             | -0.00092      | -0.0012                                | -0.0011     | -0.0017              | -0.0022*                         |
| Revenue missing (yes=1)                      | -0.22         | 0.029                                  | -0.17       | -0.33                | -0.32**                          |
| Water source                                 |               |                                        |             |                      |                                  |
| Shallow well (yes = 1)                       | 0.01          | -0.063                                 | 0.016       | -0.084               | 0.010                            |
| Deep well (yes = 1)                          | 0.047         | 0.14*                                  | 0.067       | 0.035                | -0.082                           |
| Surface water (yes = 1)                      | 0.10          | -0.043                                 | -0.15*      | -0.022               | 0.016                            |
| Recycled water (yes = 1)                     | -0.08         | 0.028                                  | 0.020       | -0.011               | 0.00016                          |
| Rain (yes = 1)                                | -0.059        | -0.17*                                 | 0.030       | -0.15*               | -0.12*                           |
| Municipal water (yes = 1)                     | -0.015        | -0.044                                 | -0.0076     | 0.033                | -0.042                           |
| Other water (yes = 1)                         | -0.014        | -0.18                                  | 0.20*       | -0.023               | -0.030                           |
| Region                                        |               |                                        |             |                      |                                  |
| Appalachian (yes = 1)                         | 0.074         | 0.03                                   | -0.18       | -0.062               | 0.0040                           |
| Midwest (yes = 1)                             | 0.024         | -0.049                                 | -0.15       | -0.32**              | -0.010                           |
| Northeast (yes = 1)                           | -0.065        | -0.053                                 | -0.37***    | -0.20*               | -0.046                           |
| Pacific (yes = 1)                             | -0.095        | -0.052                                 | -0.19       | -0.23**              | -0.025                           |
| Southeast (yes = 1)                           | -0.13         | -0.09                                  | -0.18       | -0.23*               | 0.046                            |
| Chi-square P                                  | 0.063         | 0.22                                   | 0.092       | 0.11                 | 0.52                             |
| Pseudo R²                                     | 0.13          | 0.068                                  | 0.079       | 0.083                | 0.085                            |
| Observations                                  | 252           | 252                                    | 252         | 252                  | 252                              |

P* < 0.10, ** P < 0.05, *** P < 0.01.

regions (Appalachia, Midwest, Northeast, Pacific, Southeast, and Great Plains/Mountain/South-central, with the latter excluded from the model), and dummy variables for water sources (surface, municipal, deep well, shallow well, and gray water/rain/other). For the analysis, the regions that were used were as defined in the Census of Agriculture [U.S. Department of Agriculture (USDA), 2010]. It was feasible to include all water source dummy variables in the model because some operations use multiple water sources. Missing variable indicators were used to include observations from growers who did not report annual revenue or the composition of revenue. Descriptive statistics of the data used in the probit models are shown in Table 2.
Table 5. Wald test for differences in perceptions by water source and region. Responses were collected nationally from ornamental operations by online survey. Survey responses were collected from Jan. 2012 through Mar. 2013.

| Question                                      | Water source | Region |
|-----------------------------------------------|--------------|--------|
| Reduce product loss                           | 5.36 (P = 0.37) | 4.05 (P = 0.54) |
| Increase quality                              | 4.23 (P = 0.75) | 5.96 (P = 0.54) |
| Increase efficiency                           | 6.28 (P = 0.028) | 16.11 (P = 0.01)*** |
| Reduce disease loss                           | 13.19 (P = 0.07)* | 10.36 (P = 0.17) |
| Reduce irrigation management cost             | 12.69 (P = 0.03)** | 6.64 (P = 0.25) |
| Increase ability to manage growth             | 8.30 (P = 0.31) | 17.09 (P = 0.02)** |
| Reduce monitoring cost                        | 7.70 (P = 0.17) | 7.70 (P = 0.17) |
| Cost too high                                 | 7.67 (P = 0.36) | 19.37 (P = 0.01)*** |
| Would not control irrigation correctly        | 9.19 (P = 0.10)* | 1.64 (P = 0.90) |
| Not reliable                                  | 9.17 (P = 0.24) | 16.42 (P = 0.02)** |
| Too much maintenance                          | 1.81 (P = 0.88) | 9.22 (P = 0.10)* |
| Note as efficient as current system           | 5.96 (P = 0.54) | 6.49 (P = 0.48) |

*Chi-square statistic with 7 df.
†Chi-square statistic with 5 df.

Fig. 1. Size composition (annual sales) of survey responses from an online and paper-based national survey of ornamental growers compared with U.S. ornamental industry (U.S. Department of Agriculture, 2010). Survey responses were collected from Jan. 2012 through Mar. 2013.

Probit models were estimated separately for each question by maximum likelihood using Stata (College Station, TX). Marginal effects of the explanatory variables (i.e., changes in the probability of a “yes” answer due to one unit changes in the explanatory variables) were calculated as sample averages and are reported in Tables 3 and 4. The marginal effect of a characteristic is more informative than its raw coefficient because the marginal effect gives the change in the probability of a “yes” response associated with a change in that characteristic. Wald tests were used to determine whether differences in perceptions across regions and water sources were jointly significant; the results of these tests are shown in Table 5. The significance of differences in perceptions according to individual characteristics like operation size and composition were determined using t tests. The probability values from those tests are reported along with the estimated marginal effects of these characteristics in Tables 3 and 4.

Results and discussion

There are ≈38,000 ornamental production operations in the United States (USDA, 2010). A total of 175 responses were collected for the initial, longer survey, with 31 of the respondents (23%) completing all questions. There were 336 responses to the second, shorter survey, with 279 respondents (83%) completing all questions. Missing responses and operations answering both surveys reduced the total number of usable observations to 252 for both survey phases. The sample was more heavily weighted toward large operations, in terms of income, compared with the overall population of ornamental growers reported by the Census of Agriculture (USDA, 2010) (Fig. 1), which is not surprising, since the survey was distributed via networks oriented toward commercial growers who are the most likely customers for wireless sensor networks. Growers from the Midwest were underrepresented relative to the overall population (Fig. 2), a result of having fewer contacts in that region than elsewhere.

Our sample may also have overrepresentation of more tech-savvy growers. The survey instrument was distributed primarily via listservs of state Extension Specialists and thus reached growers comfortable with computers and the Internet and those in habitual contact with extension services. Although this sample may not be representative of the population of ornamental growers as a whole, it is likely representative of potential early adopters of new technologies—which is, in fact, the relevant audience for a survey about an emerging technology.

Perceptions of benefits and limitations. Overall, respondents had positive perceptions about wireless sensor networks, with 50% or more answering “yes” to each of the questions about potential benefits (Fig. 3). Eighty-three percent of respondents believed that wireless sensor networks would increase efficiency, whereas 70% felt these networks could increase plant quality. Sixty-one percent of the respondents believed they would reduce product losses.

Negative perceptions of wireless sensor networks were less pronounced (Fig. 4). Cost was seen as the biggest drawback: 82% of respondents believed that these systems would be too expensive. Reliability was the second biggest concern, cited by half of the respondents. Anecdotally, for the
growers involved in the project, we have found that both return on investment (cost) and reliability indicate that these systems would be beneficial for growers to adopt (Lichtenberg et al., 2013).

**Variations in Perceptions by Operation Size and Composition.** We explored whether perceptions of wireless sensor networks differed according to operation size and composition by examining the estimated marginal effects of operation size in acres, annual revenue, and percentages of income derived from greenhouse, container, and field operations. The marginal effect of a characteristic measures how a change in that characteristic affects the probability of a “yes” response to a question. For example, as can be seen from Table 3, growers with larger operations as measured by revenue were more likely to believe that wireless sensor networks would improve their ability to manage their irrigation systems, as indicated by the fact that each additional million dollars in revenue increased the probability of a “yes” answer to this question by 4% points (Table 3). These estimated marginal effects suggest that larger operators are more likely to be confident in the efficiency of the hardware used to deliver irrigation water but less likely to be confident about the “software”—human or automated—used to make irrigation decisions. Thus, wireless sensor networks’ current main attraction for these growers appears to derive mainly from their ability to provide better information in real
time rather than their potential control capabilities.

The principal concern of larger operators appears to be maintenance: An additional million dollars in average revenue was associated with an almost 2% point increase in the probability of a “yes” answer to the question about whether wireless sensor networks would require too much maintenance. A possible explanation is that the probability that at least one component of the sensor network system will malfunction increases as the number used increases. Larger operations, of course, need to use a larger number of sensors and are thus more likely to experience malfunctions.

Although perceptions about the ability of wireless sensor networks to increase quality do not appear to vary by size of operation overall, they do vary with the composition of the operation. Growers earning larger percentages of their gross income from greenhouse or field operations were significantly less likely to believe that wireless sensor networks can increase quality: An additional 1% of gross income derived from either source reduced the probability of a “yes” answer to this question by 4.7% points.

**Regional variations in perceptions.** There were relatively few significant differences in perceptions about wireless sensor networks across growing regions (Table 5). Growers in the Appalachian, Midwest, Northeast, Pacific, and Southeastern regions were significantly more likely to believe that wireless sensor networks could increase their ability to manage growth compared with growers in the Great Plains/Mountain/South-central states. Growers in the Midwest were also significantly more likely to believe that wireless sensor systems could increase their irrigation efficiency. Both sets of results suggest that growers in these regions were more likely to face water restrictions—because of cost, quality, or usage restrictions—than growers elsewhere in the United States. As water becomes more scarce and thus more expensive, the benefits of wireless sensor networks are likely to increase.

There were relatively few significant differences in perceptions about wireless sensor systems between growers using different water sources (Table 5). Growers using municipal water were more likely to believe that wireless sensor systems could increase their ability to manage growth. This result holds regardless of location. As noted above, a possible explanation is that municipal water users were likely to be limited due to cost. In contrast, growers using shallow wells were significantly less likely to believe that wireless sensor systems could increase irrigation management costs, whereas growers using recycled water were statistically more likely to believe that wireless sensor systems could reduce irrigation management costs. A possible explanation is that water—and thus irrigation—was relatively inexpensive and abundant for growers using shallow wells and likely more expensive and scarce for growers using recycled water. Finally, growers using well or surface water were significantly more likely to believe that wireless sensor systems could reduce disease—at any rate, regardless of location. It is possible that surface water users were concerned about irrigation run-off contaminating their irrigation ponds. It is also likely that well users were pumping water from wells into storage/irrigation ponds so these two water sources would be linked.

**Conclusions**

We asked ornamental growers across the nation what they saw as potential benefits and limitations of wireless sensor systems as a means of assessing the likely state of acceptance of this technology at the time of its initial introduction. Although most growers had minimal information about these types of systems and the potential impacts they could have at their operation, their perceptions were overwhelmingly positive, with majorities of respondents believing that wireless sensor systems could increase irrigation efficiency, improve product quality, reduce product losses, reduce irrigation management costs, reduce disease prevalence, increase ability to manage growth, and reduce monitoring costs. Fewer growers believed that wireless sensor systems could reduce monitoring costs than believe in the other benefits of these systems. There is some irony in that perception since wireless sensor systems enable transmission of real-time information about substrate moisture status so that one might expect reductions in monitoring cost to be the most obvious benefit. Even so, only half of respondents believed that these systems could reduce monitoring costs.
Cost and reliability were the major concerns with this type of technology. Concerns about reliability increase with operation size, perhaps because they were more likely to experience failure of at least one component simply because they needed to use more sensors. Cost and reliability were the only concerns expressed by half or more of the respondents, suggesting that positive perceptions of this technology far outweigh negative ones. Nevertheless, making wireless sensor systems affordable and robust will be critical determinants of the speed and reach of adoption of this technology. Research being conducted in ornamental growing operations suggest that costs are modest (when financed at interest rates available to small businesses) and gains in profitability are substantial, so that payback periods are short (Belayneh et al., 2013; Lichtenberg et al., 2013). This research, along with the pre-introduction perceptions documented in our survey, provides ground for optimism that acceptance of this technology could be rapid and widespread.

**Literature cited**

Belayneh, B.E., J.D. Lea-Cox, and E. Lichtenberg. 2013. Costs and benefits of implementing sensor-controlled irrigation in a commercial pot-in-pot container nursery. HortTechnology 23:760–769.

Chappell, M., S.K. Dove, M.W. van Iersel, P.A. Thomas, and J. Ruter. 2013. Implementation of wireless sensor networks for irrigation control in three container nurseries. HortTechnology 23:747–753.

Kohanbash, D., G. Kantor, T. Martin, and L. Crawford. 2013. Wireless sensor network design for monitoring and irrigation control: User-centric hardware and software development. HortTechnology 23:725–734.

Lea-Cox, J.D. 2012. Using wireless sensor networks for precision irrigation scheduling, p. 233–258. In: M. Kumar (ed.). Problems, perspectives and challenges of agricultural water management. 19 Sept. 2013. <http://www.intechopen.com/books/problems-perspectives-and-challenges-of-agricultural-water-management/using-sensor-networks-for-precision-irrigation-control>.

Lea-Cox, J.D. and B. Belayneh. 2012. Irrigation complexities: Using sensor networks for real-time scheduling in commercial horticultural operations. Irr. Assn. Ann. Conf., Orlando, FL, 2–6 Nov. 2012.

Lea-Cox, J.D., G.F. Kantor, W.L. Bauerle, M.W. van Iersel, C. Campbell, T.L. Bauerle, D.S. Ross, A.G. Ristvey, D. Parker, D. King, R. Bauer, S.M. Cohan, P. Thomas, J.M. Ruter, M. Chappell, M. Lešky, S. Kampf, and L. Bissey. 2010. A specialty crops research project: Using wireless sensor networks and crop modeling for precision irrigation and nutrient management in nursery, greenhouse and green roof systems. Proc. Southern Nursery Assn. Res. Conf. 55:211–215.

Lea-Cox, J.D., W.L. Bauerle, M.W. van Iersel, G.F. Kantor, T.L. Bauerle, E. Lichtenberg, D.M. King, and L. Crawford. 2013. Advancing wireless sensor networks for irrigation management of ornamental crops: An overview. HortTechnology 23:717–724.

Lichtenberg, E., J. Majsztrik, and M. Saavoss. 2013. Profitability of sensor-based irrigation in greenhouse and nursery crops. HortTechnology 23:770–774.

Majsztrik, J.C., A.G. Ristvey, and J.D. Lea-Cox. 2011. Water and nutrient management in the production of container-grown ornamentals. Hort. Rev. 38:253–297.

Majsztrik, J.C., E.W. Price, and D.M. King. 2013. Environmental benefits of wireless sensor-based irrigation networks: Case-study projections and potential adoption rates. HortTechnology 23:783–793.

Nemali, K.S. and M.W. van Iersel. 2006. An automated system for controlling drought stress and irrigation in potted plants. Sci. Hort. 110:292–297.

U.S. Department of Agriculture. 2010. 2007 Census of agriculture: Census of horticultural specialties. Vol. 3. Special Studies Part 3. U.S. Dept. Agr., Washington, DC.