Engineering, Structures and Innovations

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Development of a Cost-effective Automated Oxygenated Irrigation System

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Significance to the Industry: Plant pathogens are responsible for billions of dollars in crop losses each year. In container-grown ornamental operations, plants are densely spaced and require almost daily overhead irrigation compared to agricultural crops, creating a highly suitable environment for disease. While there are chemical options for controlling plant disease, they can be costly and pathogens can build resistance to the chemicals. By oxygenating irrigation water, container-grown plants would be exposed to more oxygen in the root zone, potentially reducing pathogenicity and providing an alternative to chemical control.

Nature of Work: Irrigating crops can be one of the most difficult jobs in nursery production and requires careful attention. Over-irrigating reduces oxygen content in the root zone (6) creating anaerobic conditions, thus limiting the availability of oxygen for plant respiration (3). Plant respiration increases with higher temperatures, which can be a serious problem in container-grown plants where root ball temperatures in the summer can exceed 100°F (37.8°C). This results in a greater oxygen demand by the plant, leading to oxygen depletion in the root zone and a more favorable environment for *Phytophthora* and *Pythium* (4, 7). Chérif et al. (2) reported reduced shoot and root growth of tomato plants and a favorable environment for disease in root zones below 3 $mg{\cdot}L^{-1}$. Moreover, by oxygenating irrigation water plants would be exposed to more oxygen in the root zone which could reduce pathogen invasion. In a previous experiment, irrigating container-grown lavender with 13 $mg{\cdot}L^{-1}$ dissolved oxygen increased root growth compared to plants irrigated with 7 $mg{\cdot}L^{-1}$ (10). In this experiment the authors hand applied the two irrigation treatments. While they did see increased root growth this was not the most efficient way to irrigate container-grown plants. To efficiently irrigate with oxygenated water an automatic irrigation system is needed. However, developing an automated irrigation system to deliver irrigation water with specific dissolved oxygen levels can be a complicated process. Ehret et al. (5) tested four dissolved oxygen levels (2 $mg{\cdot}L^{-1}$, 5 - 6 $mg{\cdot}L^{-1}$, 16 $mg{\cdot}L^{-1}$, and 30 - 40 $mg{\cdot}L^{-1}$) and reported a 20 - 70% reduction in dissolved oxygen levels from the tank to the emitter with 16.9 $mg{\cdot}L^{-1}$ being the highest recorded. Therefore, our objective was to develop an efficient, cost-effective automatic irrigation system to deliver a range of specific dissolved oxygen levels.

A drip irrigation system was constructed using basic supplies: battery operated 4-hose connector Orbit irrigation timers, polyethylene ½” tubing, Netafilm emitters (1 gph), Little Giant submersible pumps, and ¾” PVC pipe. To elevate the dissolved oxygen level of our irrigation water, we used two oxygenators (The Oxygenator, O2 Marine Technologies, Shorewood, MN). The oxygenator uses hydrolysis to split the water molecule into oxygen and hydrogen gas; oxygen molecules are quickly absorbed back into the water and the hydrogen gas is released into the atmosphere.

Our irrigation source was Love’s Creek Springhouse (36°01’18.72”N, 83°51’34.19”), a natural spring creek located in Knoxville, TN. This allowed us to have a target control dissolved oxygen level between 7.0 and 7.5 $mg{\cdot}L^{-1}$ (normal level for ground water in TN), for this experiment our control level was 7.2 $mg{\cdot}L^{-1}$. We had three additional target irrigation treatments: 5 $mg{\cdot}L^{-1}$, 11 $mg{\cdot}L^{-1}$ and 13 $mg{\cdot}L^{-1}$ dissolved oxygen. Each of our irrigation treatments were derived from our control source. To lower the dissolved oxygen level from 7.2 $mg{\cdot}L^{-1}$ to our target level of 5 $mg{\cdot}L^{-1}$, compressed nitrogen was pumped into a 20 gallon polyethylene barrel for 2 minutes. To prevent nitrogen from escaping through the water surface, the compressed nitrogen was passed through a stone which produced micro-sized bubbles of nitrogen. To oxygenate the water from 7.2 $mg{\cdot}L^{-1}$ to our target level of 11 $mg{\cdot}L^{-1}$, the oxygenators were placed in a 20 gal polyethylene tank and monitored until dissolved oxygen level was greater than 11 $mg{\cdot}L^{-1}$, and then compressed nitrogen was used to lower the level to 11 $mg{\cdot}L^{-1}$. To oxygenate the irrigation water to 13 $mg{\cdot}L^{-1}$, oxygenators were placed in a 20 gal polyethylene tank, containing control irrigation water and the oxygenators were turned on for a minimum of 12 hours until reaching 13.2 $mg{\cdot}L^{-1}$. Each irrigation treatment was replicated three times through the automatic system.

Dissolved oxygen was measured for each irrigation treatment utilizing a HQ30d Portable Meter with LDO101 Rugged Optical Dissolved Oxygen Probe (HACH Company, Loveland, CO). The system was setup over three separate benches; each bench was 8 ft × 3 ft (length × width) with 16 emitters per line, per bench, spaced 6” apart. Data were analyzed using linear models with the GLIMMIX procedure of SAS (version 9.2; SAS Institute, Cary, NC). Dissolved oxygen levels were significant among all treatments based on Tukey’s Honestly Significant Difference test; therefore, data were analyzed by irrigation treatments. To determine if distance from the tank (initial level) affected dissolved oxygen levels, data were analyzed using Dunnett’s multiple comparison procedure, $\alpha = 0.05$.

Results and Discussion: We designed an automatic irrigation system that minimized the loss in dissolved oxygen levels as reported by Ehret et al. (5) and cost less than $900.00 (Fig. 1). Actual dissolved oxygen levels varied across the three trials and average measurements were 4.9 $mg{\cdot}L^{-1}$, 7.2 $mg{\cdot}L^{-1}$, 10.5 $mg{\cdot}L^{-1}$, and 13.2 $mg{\cdot}L^{-1}$; however, for simplicity target dissolved oxygen levels were reported (5.0 $mg{\cdot}L^{-1}$, 7.0 $mg{\cdot}L^{-1}$, 11.0 $mg{\cdot}L^{-1}$, and 13.0 $mg{\cdot}L^{-1}$). Target dissolved oxygen levels were significant across irrigation treatments (Table 1). Irrigation treatment with 5.0 $mg{\cdot}L^{-1}$ dissolved oxygen resulted in a 20.4% increase in dissolved oxygen level from the initial level (start level) to the last emitter. There were no differences observed in dissolved oxygen levels with the 7.0 mg·L^{-1} irrigation treatment, regardless of emitter measured. Irrigating with 11.0 mg·L^{-1} dissolved oxygen resulted in a 7.6% decrease in the dissolved oxygen level from the initial level (tank) to the last emitter. Similarly, there was a 15.9% decrease from the initial level of 13.0 mg·L^{-1} to the last emitter.

Dissolved oxygen levels are dependent on several factors, including temperature, atmospheric pressure, velocity, nutrient content in the water, light, and amount of organisms present (1). In fast moving streams, water is aerated as it flows over rocks or waterfalls, increasing the dissolved oxygen content and can become supersaturated. Supersaturated oxygen is when there is more dissolved oxygen then what is present at a state of equilibrium. This is determined by temperature of the water and atmospheric pressure. For example, at sea level (760 mmHg), groundwater water has a dissolved oxygen level of 7.56 mg·L^{-1} at 30°C and 14.62 mg·L^{-1} at 0°C (9) versus 6.9 mg·L^{-1} and 13.4 mg·L^{-1} at 2274 ft above sea level (700 mmHg) (8). Our dissolved oxygen saturation levels for this experiment were 63% (5.0 mg·L^{-1} at 29.6°C), 88% (7.0 mg·L^{-1} at 26.9°C), 133% (11.0 mg·L^{-1} at 28.7°C), and 158% (13.0 mg·L^{-1} at 25.5°C). When dissolved oxygen levels exceed the saturation point, the oxygen molecules are normally short lived. This was evident with a decrease in the dissolved oxygen levels of the two oxygenated irrigation treatments (11.0 mg·L^{-1} and 13.0 mg·L^{-1}). In contrast, the 5.0 mg·L^{-1} dissolved oxygen irrigation treatment had an increase in dissolved oxygen. Moreover, the control irrigation treatment (7.0 mg·L^{-1}) had an 88% saturation point which would explain why we did see a slight increase in dissolved oxygen levels, although it was not significant this provides more insight into the behavior of our irrigation water and automatic system. Furthermore, the results presented here suggest that the automatic irrigation system is one of several factors contributing to the increased or decreased dissolved oxygen levels, with water temperature and the properties of the water being the other factors. Further studies could evaluate an automated system based on percent oxygen saturation instead of actual dissolved oxygen levels.

Literature Cited

1. Anonymous. 2006. Dissolved oxygen: Aquatic life depends on it. Water Action Volunteers. Available at <http://watermonitoring.uwex.edu/pdf/level1/FactSeries-DissolvedOxygen.pdf.> Accessed on April 10, 2013.
2. Chérif, M., Y. Tirilly, and R.R. Bélanger. 1997. Effect of oxygen concentration on plant growth, lipidperoxidation, and receptivity of tomato roots to *Pythium* F under hydroponic conditions. Eur. J. Plant Pathol. 103:255-264.
3. Drew, M.C. and J.M. Lynch. 1980. Soil anaerobiosis, microorganisms, and root function. Ann. Rev. Phytopathol. 18:37-66.
4. Duniway, J.M. 1979. Water relations of water molds. Ann. Rev. Phytopathol. 17:431-460.
5. Ehret, D.L., D. Edwards, T. Helmer, W. Lin, G. Jones, M. Dorais, and A.P. Papadopoulos. 2010. Effects of oxygen-enriched nutrient solution on greenhouse cucumber and pepper production. Scientia Hort. 125:602:607.

6. Kläring, H.-P. and M. Zude. 2009. Sensing of tomato plant response to hypoxia in the root environment. Scientia Hort. 122:17-25.
7. Kuan, T.L. and D.C. Erwin. 1980. Predisposition effect of water saturation of soil on Phytophthora root rot of alfalfa. Phytopathology 70:981-986.
8. Lewis, M.E. 2006. Dissolved oxygen (ver. 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, sec. 6.2, June 2006. Available at <http://water.usgs.gov/owq/FieldManual/Chapter6/Archive/6.2_v2.1.9102013.pdf> Accessed on March 15, 2013.
9. Risberg, J. 2009. Low dissolved oxygen in water: Causes, impact on aquatic life – An overview. Minnesota Pollution Control Agency. Water Quality/Impaired Waters. 3.24.
10. Wilson, S.E., D.R. Cochran, and A.F. Fulcher. 2013. Container-grown lavender affected by oxygenated irrigation water. HortScience (Abstr.) In press.

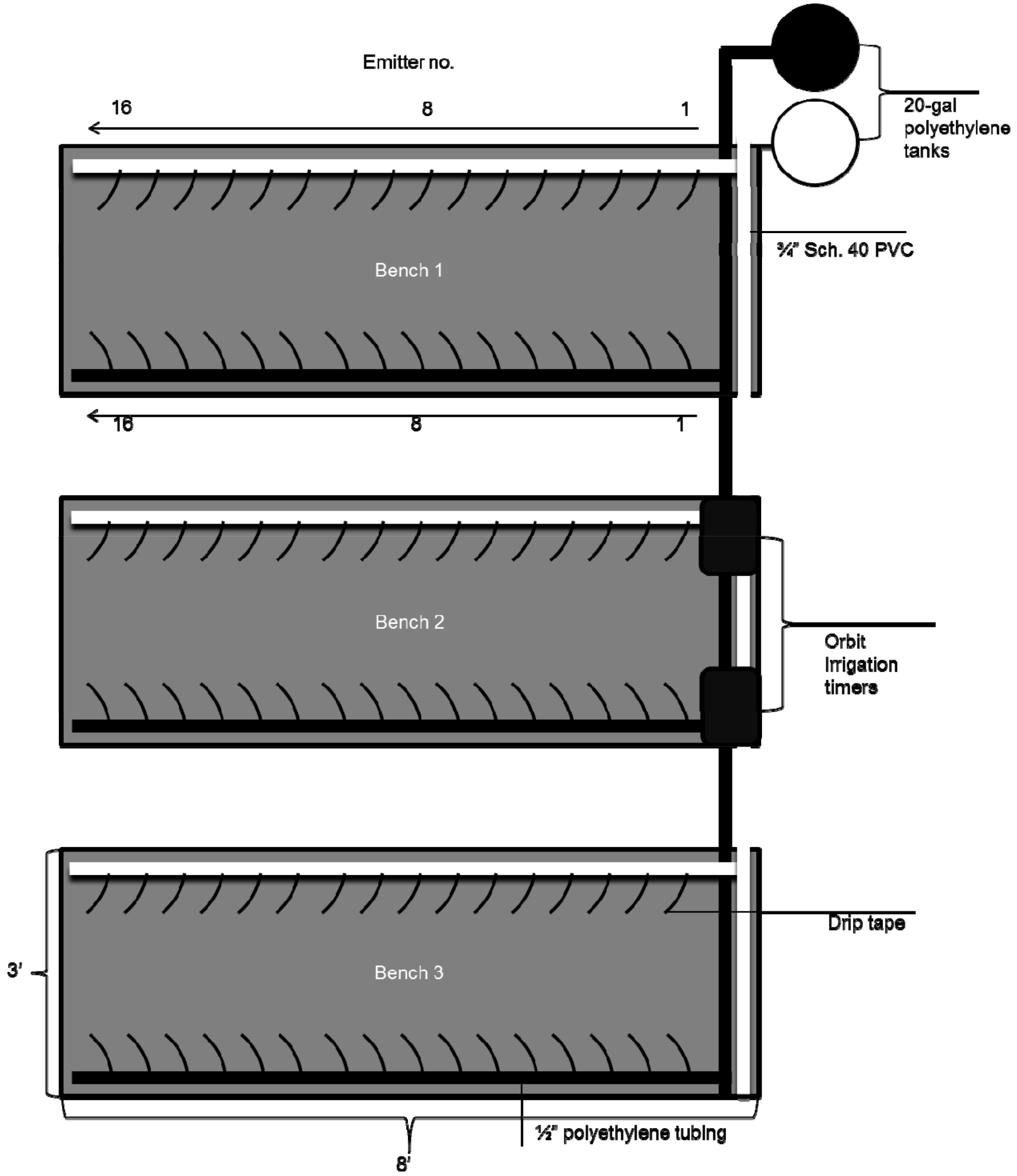

Figure 1. Automated irrigation system design.

Table 1. Testing the effect of using an automated irrigation system to deliver different irrigation treatments.

	Irrigation treatment (mg·L^{-1})[z]			
Initial level[y]	5d[x]	7c	11b	13a
Emitter[w]				
1	5.8***[v]	7.6^{NS}	9.8***	12.3^{NS}
2	5.8***	7.7^{NS}	9.7***	12.3^{NS}
3	5.8***	7.7^{NS}	9.8***	12.1^{NS}
4	5.8***	7.7^{NS}	9.9***	12.1^{NS}
5	5.8***	7.7^{NS}	9.8***	12.2^{NS}
6	5.8***	7.6^{NS}	9.8***	12.0^{NS}
7	5.8***	7.6^{NS}	9.9***	12.1^{NS}
8	5.8***	7.6^{NS}	9.8***	12.1^{NS}
9	5.8***	7.6^{NS}	9.8***	12.0*
10	5.8***	7.6^{NS}	9.9***	11.9*
11	5.8***	7.5^{NS}	9.9***	11.8*
12	5.8***	7.5^{NS}	9.9***	11.8*
13	5.8***	7.5^{NS}	9.9***	11.7**
14	5.8***	7.4^{NS}	9.9***	11.6**
15	5.8***	7.4^{NS}	9.8***	11.5**
16	5.9***	7.1^{NS}	9.7***	11.1***

[z] Irrigation treatment: target dissolved oxygen levels were 5.0 mg·L^{-1}, 7.0 mg·L^{-1}, 11.0 mg·L^{-1}, and 13.0 mg·L^{-1}; however, actual dissolved oxygen levels varied across the three trials and average measurements were 4.9 mg·L^{-1}, 7.2 mg·L^{-1}, 10.5 mg·L^{-1}, and 13.2 mg·L^{-1}.

[y] Initial level: dissolved oxygen level of tank prior to irrigation water running through the automatic irrigation system.

[x] Means with the same letters (across columns) are not significantly different according to Tukey's honestly significant difference test, α= 0.05.

[w] Emitter: sixteen emitters on each line spaced 6" apart; 1 represents the first on the line and 16 represents the last on the line.

[v] *,**,***,NS (within columns) are significant or nonsignificant compared with the initial level based on Dunnett's multiple comparison test, $P \le 0.05$, 0.01, 0.001.

Sensor-Guided Intelligent Sprayers: Implications for Increased Worker Safety and Reduced Pesticide Use

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Significance to the Industry Pesticide use in agriculture is increasingly scrutinized, yet it is very difficult to produce plants consistently, at acceptable survival rates, and of a marketable quality level without some use of pesticides. The conventional method of applying pesticides in tree nurseries is inefficient. Less than 30% of pesticides applied by air-assisted sprayers are intercepted by the target crop. Two intelligent spray systems were developed to address spray application inefficiency: a hydraulic boom sprayer for young, narrow trees and an air assisted sprayer for wider trees in nurseries and orchards. Within the spray range, both intelligent sprayers had the capability to adjust spray outputs to provide the required quantity of spray deposition. In a comparison of variable-rate, intelligent- and conventional rate hydraulic boom systems, pest control was generally not affected by sprayer type or was better for the intelligent sprayer.

Nature of Work Pests pose a substantial threat to the sale of nursery crops and increase the cost of producing ornamental crops. As an example, in North Carolina the green industry reported annual losses of $91M due to insects and diseases (Anonymous, 2005). Losses due to plant disease in Georgia nurseries were estimated to be $43.4M in 2007 (Martinez, 2008).

Pest management is challenging for nursery crop producers for several reasons. One basic challenge is the large number of plant taxa produced by growers and their associated pest complexes. Also complicating pest management is the intensive manual labor required during production, necessitating that workers be in production areas and have physical contact with plants. Pest management in nurseries is also difficult because unlike agronomic crops, nursery crops are sold based on visual appeal, not yield, and consumers have essentially a zero tolerance threshold for pests (Glasgow, 1999; Townsley-Brascamp and Marr, 1995). Finally, because many nursery crops can be a long-term crop and are subjected to pruning, they often change in size and foliar density dramatically throughout the growing season and years.

Pesticides, as part of an Integrated Pest Management program, can serve an important role in decreasing plant mortality, maintaining plant quality to a market acceptable level, and complying with plant trade requirements, which facilitates national and international trade (Cloyd, 2008). However, pesticide use and misuse pose a threat to human health, as was notably documented for the Aral Sea and its drainage basin (UNEP, 1993). Even isolated use of systemic pesticides can have unintended environmental consequences. For example, recently an ill-timed dinotefuran application killed tens of thousands of bees (Anonymous, 2013). By refining pesticide applications, environmental and human risk from pesticide use could be reduced.

Air-assisted sprayers are conventionally used to apply insecticides, miticides and fungicides to field-grown nursery crops. A typical application rate is based on 100 gallons per acre and thus each application uses a significant amount of water. The spray volume is rarely adjusted based on plant size or plant growth stage. Air-assisted sprayers have very low spray application efficiency. Less than 30% of pesticide applications are intercepted by the nursery canopy (Zhu et al., 2006). The rest is lost to ground vegetation, non-target plants in the nursery, or is lost as drift where it can land on soil or water or ultimately enter water through erosion or runoff. Application of broad-spectrum pesticides by an air-assisted sprayer has been linked to a reduction of naturally occurring biological control organisms and an increase in arthropod pest populations in urban (Raupp et al., 2001) and nursery (Frank and Sadof, 2011) ecosystems.

Increasing spray application efficiency could protect plant quality while enhancing worker safety due to the significant reduction of application rates. Worker safety would be improved by reducing active ingredient residue on plant surfaces and air contamination. Additionally, because of the increased efficiency, the tank would be refilled less frequently, reducing opportunities for the spray applicator to come into contact with concentrated pesticides during mixing. Increasing efficiency would reduce total active ingredient applied as well as decrease the water footprint of each pesticide application compared with current pest management practices, leading to greater environmental quality. There is a need for advanced sprayers that automatically attenuate spray outputs based on canopy characteristics. Therefore, our objectives were to design and test two intelligent spray delivery systems that would increase spray application efficiency by automatically adjusting output to canopy characteristics in real time while maintaining an acceptable level of pest control and plant quality.

Two variable-rate output spray systems that integrate plant characteristics in real time were developed for nursery applications: an air assisted sprayer for wide species of nursery and fruit tree crops (Chen et al., 2012) and a hydraulic boom sprayer for young, narrow trees such as liners (Jeon and Zhu, 2012). Both sprayers are sensor-guided, employing a high-speed laser scanning sensor for the air assisted sprayer and an ultrasonic sensor operating at a 20 Hz detecting frequency for the boom sprayer. Each sprayer has an automatic controller consisting of a computer program, a signal generation and amplification unit, and pulse width modulated solenoid valves, but different algorithms and circuit designs. The sensors detect the presence or absence of a plant, plant architecture, canopy volume, and tractor speed, and controllers manipulate the solenoids to produce variable-rate spray outputs based on plant characteristics and plant occurrence in real time. Sprayers were developed at the USDA-ARS Application Technology Research Unit in Wooster, Ohio. Sprayers were tested in several laboratory and field experiments in Ohio and Oregon in 2011 and 2012 and are currently being tested for pest control efficacy and sprayer reliability in commercial nurseries in Ohio, Oregon, and Tennessee.

<u>Variable-rate air-assisted sprayer performance:</u> Spray consumptions between the intelligent sprayer and a conventional air-assisted sprayer in an orchard were compared at three different growth stages. The comparison tests were conducted in April when trees just started breaking dormancy, in May when trees developed half of the full canopy, and in June when trees developed a full canopy. Application rate for the conventional sprayer was 470 L/ha (50 gpa), which was determined by a tree-row volume method (Chen et al., 2012; Jenkins and Hines, 2003).

<u>Variable-rate hydraulic boom sprayer performance:</u> Tests were conducted to verify deposition uniformity inside canopies with various sizes of trees at different travel speeds. The test plot consisted of two rows of six different tree species (red maple, *Acer rubrum* 'Franksred'; European hornbeam*, Carpinus betulus*; Sargent's crabapple, *Malus sargentii;* purpleleaf sand cherry, *Prunus* x *cistena;* Freeman maple, *Acer* x *freemanii* 'Jeffersred'; Japanese maple, *Acer palmatum*). Tree species had different heights that ranged from 0.8 to 2.5 m, and caliper measured at 15.5 cm above the ground ranged from 0.5 to 5.4 cm. The travel speeds for the test were 3.2, 4.8, 6.4, and 8.0 km/h. Spray deposition and coverage of the hydraulic boom sprayer were compared with 60 and 100 gpa constant-rate applications. Water sensitive papers were mounted inside canopies to measure the spray coverage, and a fluorescent tracer, Brilliant Sulfaflavine, was mixed with water to form spray solution to quantify spray deposits.

<u>Variable-rate hydraulic boom sprayer pest control:</u> In Oregon, red oak (*Quercus rubra*) liners were rated seven times between June 16, 2011 and September 30, 2011 to monitor aphid levels and compare control of aphids by a conventional boom sprayer and the intelligent variable-rate boom sprayer. Trees were sprayed August 30, 2011 with Diazinon 50W (1lb/100 gal) when aphids reached the action threshold, approximately 40 aphids per leaf. Likewise, Norway maple (*Acer platanoides*) liners were rated 10 times between June 16, 2011 and September 30, 2011 to monitor powdery mildew and to compare control by a conventional boom sprayer and the intelligent variable-rate boom sprayer. Trees were sprayed on July 1 with Chlorothalonil

720 SFT (22 oz per 100 gal), July 26, 2011 with Eagle 20 EW (8 oz per 100 gal), and August 12, 2011 with 3336F (20 oz per 100 gal). The following rating system was used: 0=no sign of powdery mildew, 1=1% to 25% powdery mildew, 2=26% to 50%, and 3=51% to 100%. For both experiments, five of the newest, fully expanded leaves were examined for each of 20 trees per treatment. Each individual tree was considered a replication; individual leaves were subsamples. The innermost and outermost rows in the block were considered border rows and were not sampled. One side of the sprayer contained the intelligent system and produced variable-rate output, while the other side of the sprayer remained a conventional boom sprayer and applied the conventional constant rate.

Results and Discussion

<u>Variable-rate air-assisted sprayer performance:</u> Pesticide consumption was dramatically reduced with the variable-rate intelligent sprayer. Consumption and percent spray reduction by the intelligent air-assisted sprayer in April, May and June are shown in Figure 3. The intelligent sprayer used 140 L/ha (15 gpa) with 70% spray mixture reduction in April, 159 L/ha (17 gpa) with 66% spray mixture reduction in May, and 224 L/ha (24 gpa) with 52% spray mixture reduction in June (Figure 3). Air-assisted intelligent sprayer coverage and deposition inside canopies were more stable over different growth stages at approximately 40% coverage compared to approximately 45-90% saturated coverage for the same air-assisted sprayer (non-intelligent control) and a conventional air-assisted sprayer (data not shown). The percent reduction was based on 470 L/ha (50 gpa) used by the conventional air-blast sprayer. This is considered a half-rate application; therefore, the reduction in consumption would be even greater for a more typical conventional sprayer rate of 100 gpa.

<u>Variable-rate hydraulic boom sprayer performance:</u> Spray deposits and coverage inside canopies of six plant species are shown in Tables 1 and 2. Spray deposit and coverage were relatively uniform regardless of changes in the canopy size, plant morphology, and travel speed. Compared to the variable-rate boom sprayer, constant-rate applications of 60 and 100 gpa generally produced excessive spray deposition and coverage with unnecessary runoff (data not shown). Conventional spray application rates estimated with the tree-row volume method were 131, 60, 40, 36 and 28 gpa, compared with variable-rates of 38, 32, 25, 16 and 16, respectively. The variable-rate sprayer reduced spray volume up to 86.4 and 70.8% compared to a constant 100 gpa and tree-row volume estimated rate applications, respectively.

<u>Variable-rate hydraulic boom sprayer pest control:</u> Aphid populations reached the action threshold on August 30, 2011, and consequently a pesticide application was made (Table 3). Prior to this application, aphid levels were not different for the two treatments. Following the pesticide application, aphid populations decreased with no difference due to sprayer type until September 30, 2011 when the plants sprayed with the intelligent sprayer had a lower aphid population.

Prior to fungicide applications, powdery mildew infection was not different on one date (June 16, 2011) and lower for the intelligent sprayer plot on the other (June 30, 2011; Table 4). While significant, this difference, 0.15, was not considered biologically relevant or likely to bias the trial. Once fungicide applications commenced, powdery mildew ratings were not different or infection was lower for plants sprayed with the intelligent sprayer on all dates but one. On August 25, 2011, there was more powdery mildew on the intelligent sprayer-treated plants.

Laboratory and field tests demonstrated that both variable-rate intelligent sprayers controlled spray outputs by continually matching canopy characteristics, which reduced off-target losses, and has potential to drastically decrease pesticide use and associated economic inputs, increase environmental quality, and enhance worker safety. In the comparison of the variable-rate, intelligent- and conventional rate hydraulic boom systems, both insect and disease controls were largely similar or better with the intelligent hydraulic boom sprayer.

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Literature Cited

1. Anonymous. 2005. North Carolina green industry economic impact survey. North Carolina Department of Agriculture, Raleigh, NC.
2. Anonymous. 2013. Partners collaborate to protect bees in Wilsonville, cause of bee death determined. Oregon Department of Agriculture, Salem, OR.
3. Chen Y., H. Zhu, and H.E. Ozkan. 2012. Development of variable-rate sprayer with laser scanning sensor to synchronize spray outputs to tree structures. Transactions of the ASABE. 55(3):773-781.
4. Cloyd, R. 2009. Pesticide use in ornamental plants: what are the benefits? Pest Mgt Sci. 65:345-350.
5. Frank, S. and C. Sadof. 2011. Reducing insecticide volume and nontarget effects of ambrosia beetle management in nurseries. J. Econ. Ent. 104(6):1960-1968.
6. Glasgow, T.E. 1999. Consumer perceptions of plant quality. N.C. State Univ., Raleigh, PhD Diss.
7. Jenkins, E. and R. Hines. 2003. Chapter 4: Spraying fruit. Fruit crop pest management. A guide for commercial applicators category 1C. Michigan St. Univ. 124pp.
8. Jeon, H.Y. and H. Zhu. 2012. Development of variable-rate sprayer for nursery liner applications. Transactions of the ASABE. 55(1):303-312.

9. Martinez, A. 2008. 2007 Georgia plant disease loss estimates. Univ. Georgia Coop. Ext. Serv. Pub. SB 41-20. 6 February 2009.
10. Raupp, M.J., J.J. Holmes, C. Sadof, P. Shrewsbury, and A. Davidson. 2001. Effects of cover sprays and residual pesticides on scale insects and natural enemies in urban forests. J. Arboric. 27: 203-214.
11. Townsley-Brascamp, W. and N.E. Marr. 1995. Evaluation and analysis of consumer preferences for outdoor ornamental plants. Acta Hort. 391:199-206.
12. United Nations Environment Programme. 1993. The Aral Sea: Diagnostic study for the development of an action plan for the conservation of the Aral Sea. Nairobi.
13. Zhu, H., R.C. Derksen, H. Guler, C.R. Krause, R.H. Zondag, and H.E. Ozkan. 2006. Foliar deposition and off-target loss with different spray techniques in nursery applications. Transactions of the ASABE. 49(2): 325-334.

Table 1. Mean spray deposits inside canopies of six different species from the variable-rate hydraulic boom sprayer at travel speeds of 3.2, 4.8, 6.4, and 8.0 km/h.

Trees	Spray deposit (μL/cm^2)			
	Travel speed (km/h)			
	3.2	4.8	6.4	8.0
Acer palmatum	0.78 (0.21)^z	1.08 (0.47)	1.23 (0.41)	0.97 (0.30)
Acer ‘Jeffersred’	0.67 (0.29)	0.68 (0.56)	1.13 (0.27)	0.91 (0.24)
Prunus x *cistena*	0.96 (0.34)	0.92 (0.34)	0.68 (0.21)	0.72 (0.30)
Malus sargentii	0.86 (0.35)	0.56 (0.26)	0.84 (0.30)	0.82 (0.33)
Carpinus betulus	0.77 (0.30)	0.38 (0.23)	0.53 (0.41)	0.49 (0.25)
Acer ‘Franksred’	1.21 (0.60)	0.88 (0.46)	0.82 (0.31)	0.97 (0.41)
Mean	0.90 (0.41)	0.72 (0.43)	0.81 (0.38)	0.79 (0.35)

^{z}values in parenthesis present the standard deviation.

Table 2. Mean spray coverage inside canopies of six different species from the variable-rate hydraulic boom sprayer at travel speeds of 3.2, 4.8, 6.4, and 8.0 km/h.

Trees	Spray coverage (%)			
	Travel speed (km/h)			
	3.2	4.8	6.4	8.0
Acer palmatum	13.0 (4.5)^z	20.4 (10.8)	19.4 (8.6)	18.2 (9.6)
Acer 'Jeffersred'	12.4 (6.1)	14.4 (26.6)	16.2 (7.3)	18.8 (6.8)
Prunus x *cistena*	12.3 (8.8)	13.3 (8.0)	10.4 (7.9)	8.3 (6.5)
Malus sargentii	15.8 (9.5)	10.9 (5.8)	11.9 (7.0)	14.7 (6.7)
Carpinus betulus	14.9 (8.9)	9.2 (8.7)	6.8 (5.5)	6.7 (5.1)
Acer 'Franksred'	18.5 (8.3)	14.5 (7.4)	13.7 (8.5)	16.6 (8.0)
Mean	14.5 (5.1)	13.8 (5.5)	13.1 (6.0)	13.9 (6.4)

^{z}values in parenthesis present the standard deviation.

Table 3. Comparison of aphids on red oak trees sprayed with the variable-rate or conventional boom sprayer in a commercial nursery.

Date	Average number of aphids	
	Variable-rate	Conventional
6/16	0.0 a^y	0.0 a
8/4	2.3 a	1.8 a
8/18	11.6 a	9.1 a
8/30	46.1 a	39.5 a
9/8^z	0.6 a	0.4 a
9/15	0.4 a	0.1 a
9/30	0.3 b	3.4 a

^{z}8 days following Diazinon insecticide application.
^{y}Values in a row followed by the same letter are not significantly different at the 0.05 level.

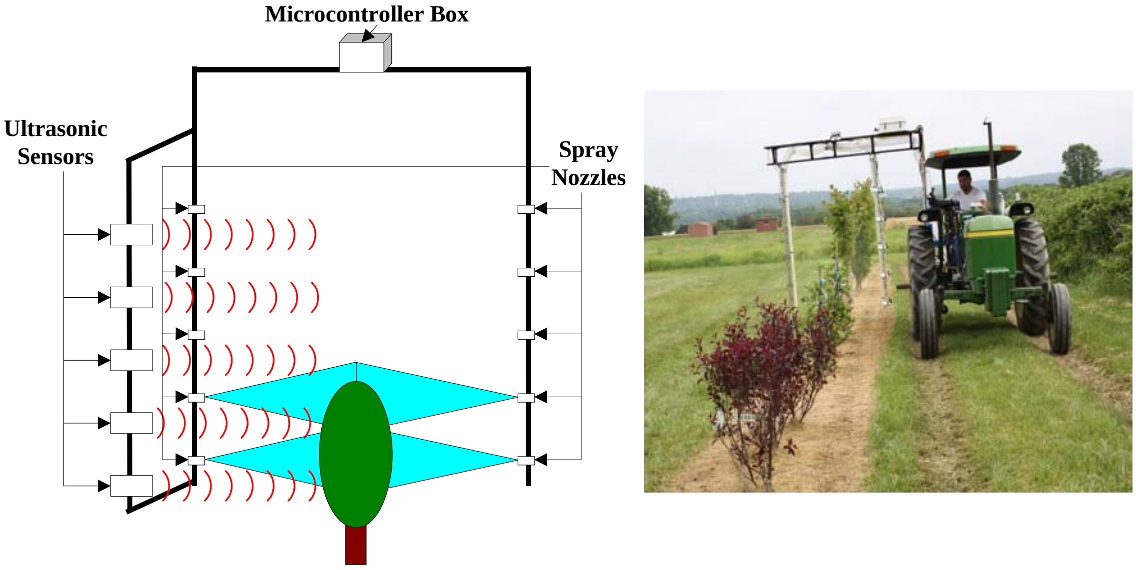
Table 4. Comparison of powdery mildew infection on Norway maple trees sprayed with the variable-rate or conventional boom sprayer in a commercial nursery.

Date	Average disease rating	
	Variable-rate	Conventional
6/16	0.06 a[w]	0.05 a
6/30	0.52 b	0.67 a
7/6[z]	0.79 a	0.84 a
7/14	0.99 a	1.00 a
7/26	1.01 a	1.08 a
8/1[y]	0.68 b	0.84 a
8/11	0.12 a	0.17 a
8/18[x]	0.56 a	0.47 a
8/25	0.83 a	0.61 b
9/30	1.10 b	1.70 a

[z], [y], [x] Five, six, and six days following Chlorothalonil 720 SFT, Eagle 20 EW, and 3336F, respectively.

[w] Values in the same row followed by the same letter are not significantly different at the 0.05 level.

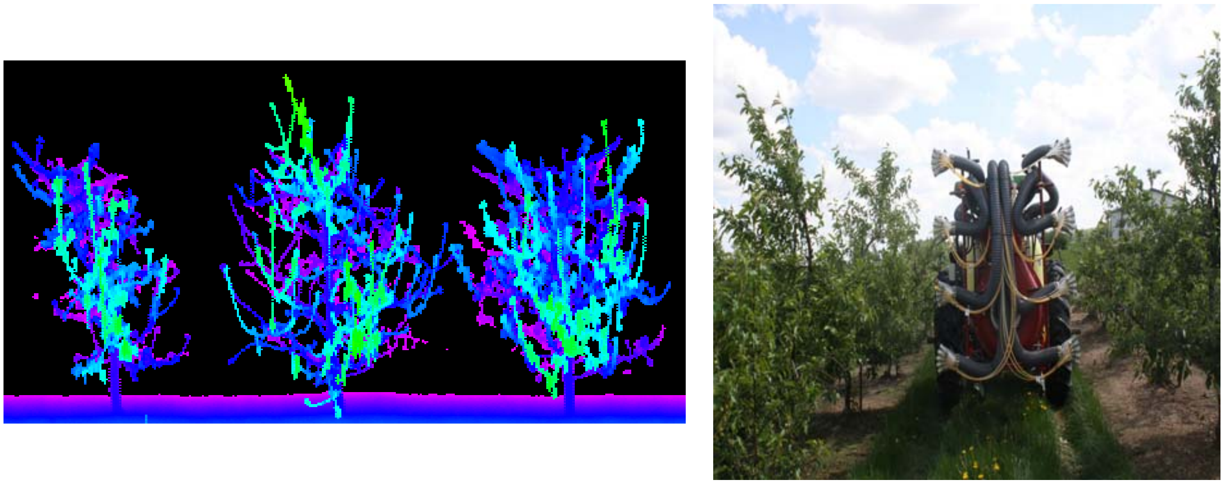
Figure 1. Ultrasonic sensor-controlled hydraulic boom sprayer to provide variable-rate functions based on tree size, shape and occurrence



(a) Schematic diagram of ultrasonic sensors to detect canopy and control spray nozzles

(b) Ultrasonic sensor-controlled variable-rate sprayer in a laboratory field

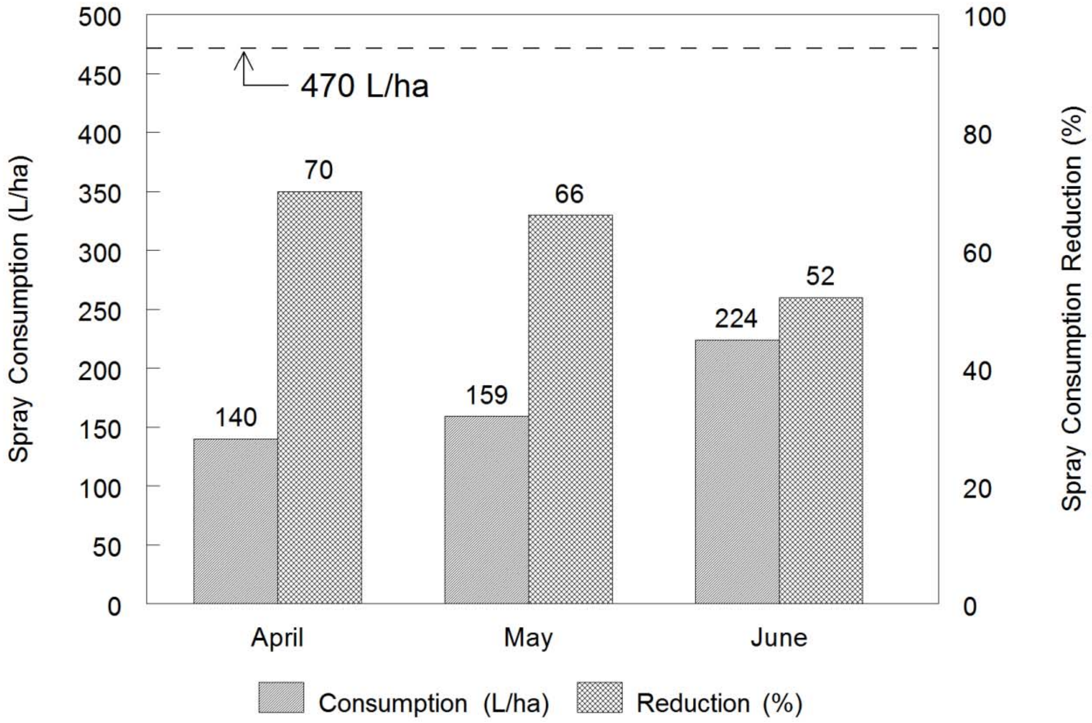
Figure 2. Laser scanning, sensor controlled air-assisted sprayer to provide variable-rate functions based on tree sectional canopy volume, density and occurrence.



(a) Images of trees scanned by a laser scanning sensor

(b) Laser-scanning sensor-controlled air assisted sprayer

Figure 3. Spray consumption and percent reduction from intelligent sprayer, compared with the conventional 470 L/ha (50 gpa) spray application rate in April, May and June.



Plant Count for Container-grown Plants Using an Aerial Boom and Object-based Software

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Nature of Work: In general, the nursery industry lacks a good inventory control system (1). Collection of plant inventory data in nurseries is time consuming, expensive and may be inaccurate. Most nursery growers use manual methods for the collection of inventory data. Due to the high cost and time involved in manually counting plants, growers often count only a portion of their crop. Automating the plant inventory process may potentially decrease labor inputs, increase precision and save money.

The experiment was conducted on 13 and 14 November, 2012 at the Citrus Research and Education Center (University of Florida, FL, USA). A block of 100 # 1 containers were spaced in a 10 × 10 square grid. Containers of perennial peanut (*Arachis glabrata* Benth) were positioned on black polypropylene fabric.

A 60 foot articulated boom was used in this study. A Canon EOS 5D Mark II camera (5,616 × 3,744 pixels) was mounted to an aluminum pole that extended 2 m horizontally beyond the bucket. The camera was triggered remotely. Photographs were taken at an elevation of 30, 40, 50, and 60 ft. For each boom height, plants were spaced to obtain 0.8, 1.1, 1.6, 2.5 and 3.3 plants per square foot. Four or more photographs were taken at each elevation. Four photographs were analyzed per each combination of boom altitude and plant density, the first photograph was used for algorithm development, and the algorithm was applied to the remainder of the photographs in that treatment.

The object based image analysis approach was adopted to extract plants in a two-step process involving image segmentation and classification based on spectral and contextual information (2). A segmentation resulted in vector boundaries of individual plants, when combined with spectral values for each plant and contextual information between plants, thematic classification was generated by applying Feature Analyst v.5.0 (Overwatch Textron Systems, Austin, TX) for ArcGIS software (Esri, Redlands, CA) to the selected image.

For classifying plants, the genetic ensemble feature selection (GEFS) neural network algorithm (3), implemented in Feature Analyst, was used. The algorithm created a boundary file around objects of interest (plants) using the contextual and spectral information provided in the form of training sets. The end point for the iteration process was signaled beyond which the number of plants obtained through classification process again started to increase. At that stage, the resultant polygonal shape-files were converted to point shape-files and the numbers of points designating plant positions were recorded (Figure 1). Algorithms were developed using the following parameters:

1. Creation of a training feature class. Training shape: circle. The circles covered about 95% of the containers circle area. Number of training circles: 6.
2. Supervised learning was applied, using none histogram and Manhattan 5 as a pattern.
3. When removing clutter procedure was applied, 10 correct features were selected: same positions where the training circles were located and 4 additional features were added at fixed positions. Per each correct feature, the 3 closest incorrect features to it were selected. Additionally, incorrect features with random shapes that do not contain pixels that were part of a plant were selected as incorrect.
4. Another procedures such as convert to metrics, smoothing, aggregation, eroding and dilate were used as needed.

Once the algorithm was developed, is applied to the rest of the images as an

Automated Feature Extraction (AFE) model. One algorithm was developed per each combination of boom altitude and distance between canopies.

Results and Discussion: The overall accuracy of the peanut count was 97.6% (Table 1). Except for a plant density of 2.5 plants/ft^2, there does not appear to be an affect of boom height on counting accuracy when images are analyzed using Feature Analyst. For a plant density of 2.5 plants/ft^2, lowering the boom height from 50 to 30 feet (increasing spatial resolution), caused a decrease in counting accuracy. Across all plant densities and boom heights, there does not appear to be a consistent trend related to plant count accuracy, however the lowest count accuracies were observed for a plant density of 1.6 plants/ft^2.

Table 1. Effect of plant density and boom height on plant counting accuracy

Boom Height	Plant density (Plants per square foot)					Overall
(feet)	0.6	0.8	1.1	1.6	2.5	Mean
30	100.0	99.0	99.7	93.6	90.1	96.5
40	100.7	101.3	100.0	91.0	91.7	96.9
50	100.0	100.3	100.0	91.3	100.3	98.4
60	100.0	99.4	99.5	91.7	103.3	98.8
Overall Mean	100.2	100.0	99.8	91.9	96.3	97.6

*Values are expressed as percentages.

Summary: The results provide a foundation for future work using MRRSS and object based analysis software to count plants in an open-field nursery.

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Literature Cited

1. Harkess, R.L. 2005. RFID technology for plant inventory management. Proc. Southern Nurs. Assoc. Res. Conf. 50:369-371.
2. Blaschke, T. and G.J. Hay. 2001. Object-oriented image analysis and scale-space: Theory and methods for modeling and evaluating landscape structure, *International Archives of Photogrammetry and Remote Sensing*, 34(4/W5):22-29.
3. Blundell, J.S. and D.W. Opitz. 2006. Object recognition and feature extraction from imagery: The feature analyst approach, *Proceedings of the 1st International Conference on Object-based Image Analysis*, Austria. URL: http://www.isprs.org/proceedings/XXXVI/4-C42/Papers/09_Automated%20classification%20Generic%20aspects/OBIA2006_Blundell_Opitz.pdf (last date accessed: 28 November, 2011).

Fig. 1. Example of analysis output for images taken at 30 feet with a plant density of 2.5 plants/ft^2. Yellow dots represent plants counted by Feature Analyst.