Costs Associated With Mitigating Boxwood Blight During Nursery Production in the U.S.[1]

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Abstract

Three scenarios commonly used for nursery production of boxwood (Buxus L. spp., Buxaceae) in #3 containers [11 L (3 gal)] in the U.S. were modeled based on published best management practices and grower interviews. Detailed inventories of material inputs, equipment use, and labor were developed from the production protocols for each of those scenarios and a partial budgeting analysis was conducted to determine the impact of individual components on the economic costs of the finished shrubs at the nursery gate. The total variable costs of each plant from Scenario A (from propagation tray to #1 container to #3 container) were $8.98. Scenario B (propagation tray to the field and back to #3 container) resulted in variable costs of $9.19 and takes a year longer in production than the other two models. Scenario C (propagation tray to #1 container bumped up into a #2 container and finally to a #3 container) incurred variable costs of $11.26 per plant. Labor comprised the greatest share of variable costs in each of the three scenarios, while containers, transplants (including transplanting labor), irrigation, and fertilization inputs and associated activities accounted for the greatest portion of materials costs in each scenario. Pruning, assembling orders and loading trucks, applying plant protection products, and chlorination were other important components of variable costs of each scenario.

Index words: nursery crops, landscape horticulture, variable costs, boxwood blight mitigation.

Significance to the Horticulture Industry

The green industry remains an important contributor to the U.S. economy and to individual states and regions. The green industry is extremely broad-based, with the landscape services and wholesale-retail trade sectors existing in virtually all communities in the nation. Boxwood shrubs represent an important genus within the evergreen shrubs category and boxwood blight threatens to undermine its economic importance. The findings of this research are critical to our understanding of the boxwood market and issues affecting the green industry from boxwood blight. Participants in the green industry now have access to data to assist them in making strategic decisions regarding future investments to mitigate the effect of boxwood blight in their respective businesses. In addition, policymakers have better information to inform their decisions regarding efficient allocation of resources in combating this disease.

Introduction

The green industry is geographically broad-based, with landscape services and wholesale-retail trade sectors existing in virtually all communities in the nation, while the production and manufacturing sectors are increasingly concentrated in certain states and contribute to regional economies disproportionately because shipments to other states bring new money into the local economies (Hall et al. 2011). The estimated total economic contributions of the U.S. green industry in 2018, including indirect and induced regional economic multiplier effects of exports, were $348.08 billion (Hall et al. 2020). Direct industry output (or sales revenue) for all sectors was $159.57 billion. Direct employment by green industry firms was 1,286,135 full-time and part-time jobs, and the total employment contribution (including multiplier effects) in the broader economy was 2,315,357 jobs.

Boxwood is an important ornamental plant in the U.S. green industry. With its economic importance as the number one selling evergreen shrub, it continually ranks among the top revenue-generating plants in the industry. However, in recent years, the influence of a new disease, boxwood blight, has promulgated several structural shifts among states that produce boxwood (Hall et al. 2021). Boxwood blight (*Calonectria pseudonaviculata* (Crous, J.Z. Groenew. & C.F. Hill) (L. Lombard, M.J Wingf. & Crous 2010) (Lombard et al. 2010) was first observed in the U.S. in 2011 by plant pathologists in Connecticut, Maryland, Massachusetts, New York, North Carolina, Oregon, Rhode Island, and Virginia, and has now been detected in 30 states plus the District of Columbia (Daughtrey 2019). Boxwood crops in these 30 states, accounting for about 95% of the nation's total, are now at high risk. The disease quickly destroys entire boxwood crops at production nurseries and disfigures both public/private gardens and residential/commercial landscapes, resulting in significant economic and social repercussions.

The purpose of this study was to examine the changes in boxwood production best management practices (BMPs) that have resulted from mitigating boxwood blight and the economic cost of having to integrate these new BMPs. In observing container-production systems for marketable boxwood in #3 containers in the U.S., the diversity of production systems protocols was striking. A specific objective of this study was to study the effects of incorporating BMPs associated with mitigating boxwood blight on variables costs associated with the production system components in three distinct production systems for *Buxus* species grown in a #3 container in the U.S. The different

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nursery production systems were modeled because cultural practices tend to differ regionally within the U.S. because of soil and climatic conditions, so it was hypothesized that variable costs may differ accordingly.

This research was conducted using funding received by USDA-NIFA as part of the Specialty Crop Research Initiative. The Boxwood Blight Insight Group (BBIG) is a collaborative research team involving researchers, extension specialists, and industry professionals focused on managing and mitigating boxwood blight, a devastating fungal disease affecting boxwood plants. Their efforts encompass conducting studies to understand the biology, epidemiology, and spread of the pathogen, *Calonectria pseudonaviculata*, as well as monitoring the disease in various regions and examining environmental factors influencing its spread. They develop and disseminate best practices for managing and controlling boxwood blight, including cultural practices, fungicide recommendations, and resistant plant varieties. Education and outreach are key components of their work, providing resources and training to landscapers, nursery workers, and homeowners through workshops, webinars, publications, and an informational website. The group fosters partnerships among academic institutions, industry stakeholders, and government agencies to coordinate efforts, share research findings, and develop comprehensive management strategies. Additionally, they create and update guides, fact sheets, and diagnostic tools to aid in the identification and management of boxwood blight, ensuring the latest information and recommendations are available to the public and professionals. Through these efforts, the BBIG aims to reduce the impact of boxwood blight on the horticulture industry and landscapes by promoting effective disease management and prevention strategies.

Materials and Methods

Goal, scope and functional unit. The functional unit for this study was a #3 container of *Buxus* species. The three scenarios for boxwood production were defined following general best management practices (BMPs) and validated through interviews with several nursery managers serving on a SCRI advisory panel. A detailed protocol, including a detailed inventory of materials (production inputs), labor requirements for each cultural practice, and the equipment associated with each cultural practice was defined. Of course, there are many combinations of production protocols that could be modeled for boxwood production, but these three combinations were chosen to be representative (Fig. 1) of the most common nursery production techniques representing widely accepted best management practices in the green industry in the various boxwood-producing regions across the country.

Scenario A involved sticking cuttings in September directly in 40-cell flats in a greenhouse under mist, moved to a plastic-covered hoop house the following spring, and grown for 11 months before being transplanted into #1 containers in the spring of year 2. They would be transplanted to #3 containers in the spring of year 3 and grown for 18 months before being marketed in the spring/summer of year 4.

Scenario B involved sticking cuttings in community trays under mist in September, transplanting rooted cuttings to 38-cell flats after 6 months and grown for 18 months before being transplanted to the field during the fall of year 2 and grown for 3 years before being dug bare root in the fall of year 5 and transplanted into #3 containers. They would be grown for one year in #3 containers before being marketed in the fall of year 6.

Scenario C involved sticking cuttings in community trays under mist in September, transplanting rooted cuttings to 38-cell flats after 6 months and grown for 12 months before being transplanted to #1 containers in the spring of year 2 and grown for 19 months, including two growing seasons. Plants would be transplanted from #1 containers to #2 containers in the fall of year 3, growing for 18 months before being transplanted into #3 containers and marketed the following spring (year 6) after 12 months. In all scenarios, 80% of the marketable crop would be sold in a target market window as noted above and 20% sold 6 months later. When partial crops are sold, the cost of the remaining plants has been incorporated into each model accordingly.

As mentioned, activities for each phase for the three production scenarios were inventoried in terms of materials applied, equipment used, and labor hours utilized – always the main 3 components of production inputs. Variable costs were then determined for these production inputs based on prevailing rates in the allied trade (manufacturing and distribution) sector, the cost of operating the equipment and implements used (e.g., related to fuel, lubrication, or electricity usage), as well as the labor requirements for each cultural practice performed during the production states in each model system.

In all scenarios, plastic trays, #1 and #2 containers were used 4 times, requiring steam cleaning 3 times for 1 hr each using a boiler and 1.5 hrs of labor per 7,000 flats, 8,600 #1 containers, or 6,500 #2 or #3 containers. Bottom heat to maintain an average substrate temperature of 21 C (70 F) during the winter propagation periods would be provided by a propane-fueled boiler circulating heated water through tubes under the trays as calculated for previous studies (Hall and Ingram 2014). Well water use was assumed in propagation and the impact of pumping per liner was negligible. Irrigation during production on gravel beds or in the field was assumed to be from surface reservoirs. Rooted cuttings would be pruned while in the flat using mowing equipment with a 5-hp engine. In the base scenario before BMPs to mitigate boxwood blight were incorporated, fungicides would be applied 10 times during propagation only, using a 5-hp sprayer for 10 minutes per application per greenhouse. Hoop houses were assumed to be constructed of galvanized tubing and covered with a poly film and would have a 20-year useful life. Propagation substrate consisted of 90/10 by volume of perlite and peat.

The substrate in #1, #2 and #3 containers consisted of 100% fir bark, delivered after processing, and amended with dolomitic lime at 3 $kg \cdot m^{-3}$ (0.19 lbs/ft^3) for all scenarios. The number of plants to be transplanted per cubic meter of substrate would be 130 for propagation to #1

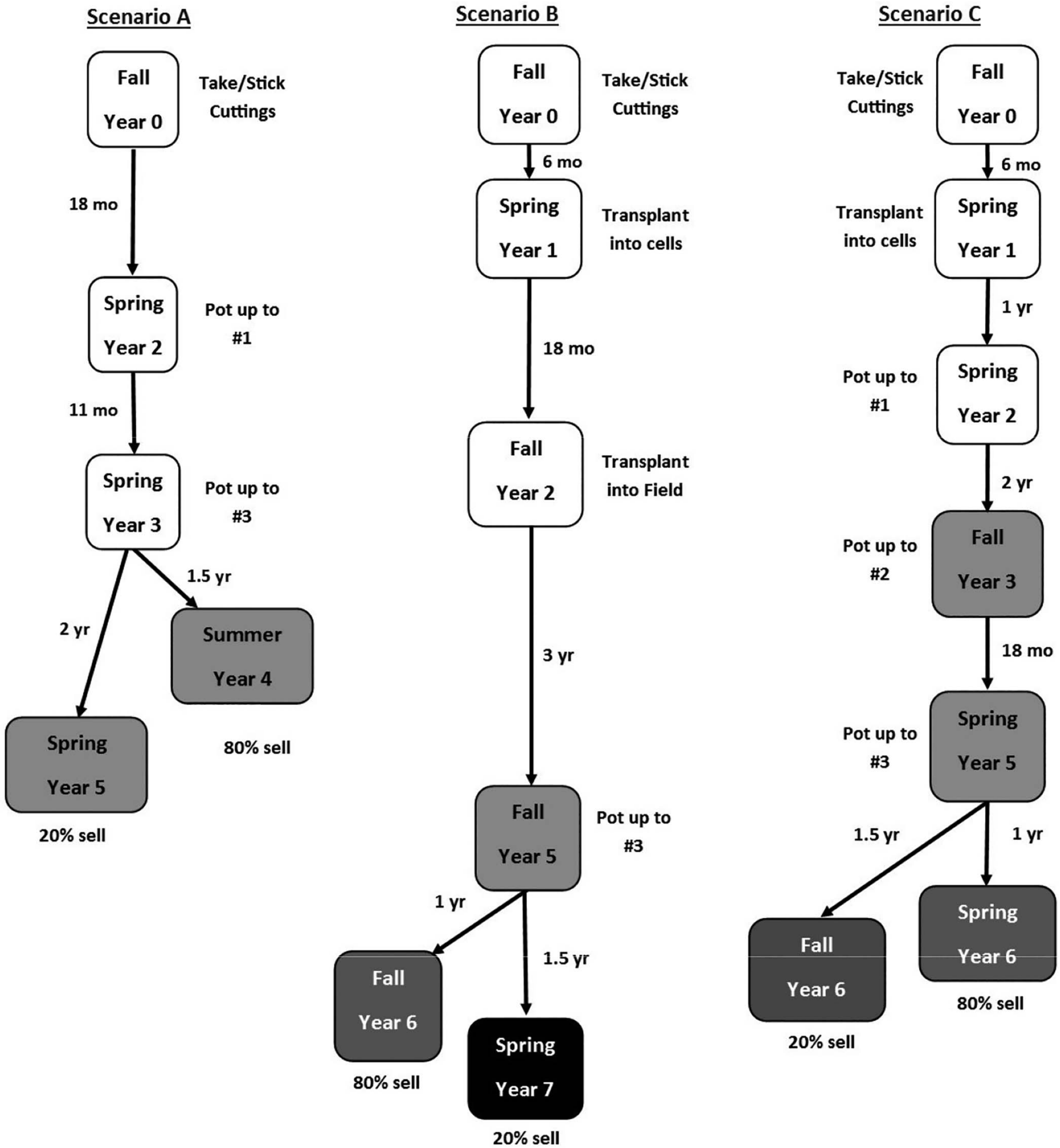

Fig. 1. Modeled production system scenarios for production of *Buxus* species in #3 containers.

containers and 260 for transplanting from #1 to #2 containers or #2 or field transplants into #3 containers. All irrigation water was assumed to be chlorinated using calcium hypochlorite injected at 2 ppm Cl. There would be an annual application of insecticide sprayed using an air blast sprayer.

Although the number of times pruned in each production phase correlates to the time in a container, pruning with a mowing machine (5-hp gasoline mower) was assumed to be at the rate of 12,000 per hour and 250 plants could be hand pruned in 1 hr. Shrinkage rates for all three scenarios were assumed to be 20% for the liners, 5% for each container phase, and 20% for the finishing field phase.

A pot-filling machine filling pots with media was used 0.5 hrs, along with a crew totaling 10 labor hrs, per 1,000 plants. Although the travel distance between the potting area and gravel beds differs significantly among nurseries, it was assumed that #1 containers would be moved to and from outdoor gravel beds with a 40-hp tractor and 3 wagons at the rate of 1,000 per hr, requiring a crew of 5.

Table 1. **Total variable costs of producing #3 boxwood plants for each of the three production systems, including baseline cultural practices plus proactive best management practices (and inputs) associated with mitigating boxwood blight.**

	Scenario A (Propagation to #1 to #3)	Scenario B (Propagation to Field to #3)	Scenario C (Propagation to #1 to #2 to #3)
Propagation stage	**($)**	**($)**	**($)**
Materials in cutting stage	$0.1068	$0.0923	$0.1597
Equipment used in cutting stage	$0.0064	$0.0269	$0.0266
Labor in cutting stage	$0.2592	$0.4885	$0.4836
Variable overhead	$0.0011	$0.0005	$0.0003
Subtotal - propagation stage	**$0.3734**	**$0.6081**	**$0.6703**
#1 Container stage			
Materials in #1 container stage	$0.4959		$0.7221
Equipment used in #1 container stage	$0.1026		$0.0799
Labor in #1 container stage	$0.3893		$0.4180
Variable overhead	$0.0010		$0.0074
Subtotal - #1 container stage	**$0.9888**	**$0.0000**	**$1.2274**
Field stage			
Materials in field nursery stage		$0.5971	
Equipment used in field nursery stage		$0.1382	
Labor in field nursery stage		$0.3864	
Variable overhead		$0.0280	
Subtotal - Field stage	**$0.0000**	**$1.1497**	**$0.0000**
#2 Container stage			
Materials in #2 container stage			$0.9646
Equipment used in #2 container stage			$0.2350
Labor in #2 container stage			$0.5291
Variable overhead			$0.0115
Subtotal - #2 Container stage	**$0.0000**	**$0.0000**	**$1.7402**
#3 Container stage			
Materials in #3 container stage	$3.7221	$3.2081	$3.7307
Equipment used in #3 container stage	$0.2492	$0.1647	$0.1906
Labor in #3 container stage	$1.7087	$1.7783	$1.4140
Variable overhead	$0.0166	$0.0077	$0.0132
Subtotal - #3 Container stage	**$5.6966**	**$5.1588**	**$5.3485**
Total cost breakdown			
Total materials costs	$4.3248	$3.8975	$5.5771
Total equipment costs	$0.3581	$0.3298	$0.5321
Total labor costs	$2.3572	$2.6532	$2.8447
Total variable overhead	$0.0187	$0.0362	$0.0324
Scouting, training, and recordkeeping costs	$1.8947	$2.2737	$2.2737
GRAND TOTAL variable costs	**$8.9535**	**$9.1903**	**$11.2601**
Baseline total variable costs (no boxwood blight mitigation costs included)	$7.1031	$7.1937	$9.1293
Added costs associated with boxwood blight mitigation per 3-gallon plant	**$1.8505**	**$1.9966**	**$2.1307**
(Percentage increase in VARIABLE costs)	**26.05%**	**27.75%**	**23.34%**

Plants in #1 containers would be transferred to #2 injection-molded containers (0.22 kg) using the same transplanting equipment at the rate of 1,000 plants per hr with a crew of 10. Transporting #1 container plants from the potting area to gravel beds would be at the rate of 1,000 per equipment hour, again with a crew of 5. Moving #2 containers between the potting area and gravel beds would be at the rate of 800 per hr with a crew of 5. Plants in #2 containers or field-grown plants would be transferred to #3 injection-molded containers (0.27 kg) using the same transplanting equipment at the rate of 800 per hr with a crew of 10. Moving #3 containers to gravel beds would be at the rate of 500 per hr with a crew of 5. The process of spacing containers or consolidating them on the same bed was assumed to be at 150 containers per labor hr. Pulling and assembling orders and loading trucks would require 10 people working 3 hrs per 1,000 plants and a tractor with wagons 1.5 hrs and a 50-hp diesel forklift running 0.25 hrs.

Energy required for overhead (electricity for general activities and gasoline for field trucks and ATVs) for each production phase was calculated from the consumption of electricity at 73 kWh·ha^{-1} (180 kwh/ac) and gasoline at 76 L·ha^{-1} (8 gal/ac) as previously published (Hall and Ingram 2015; Ingram and Hall 2014a). The inputs impacting variable costs per functional unit are presented in Tables 1 and 2. Additional details specific to each scenario are presented below.

Input materials, labor, and equipment use for Scenario A. Irrigation events (124 per year) on outdoor gravel production beds were assumed to apply 2.5 cm (1 in) each requiring 671 kW (900 hp) of pumps to cover 60-ha (148-ac) blocks at a time. Irrigation labor and a pickup truck use was calculated as 57 hrs of labor and 47 hrs of truck time per ha·yr^{-1} (1 ha = 2.47 acres).

A granular herbicide would be applied to containers on the wagon following the potting process and two additional

Table 2. **Sensitivity of the total additional variable costs that result from incorporating boxwood blight mitigation practices to changes in labor rates, materials costs, and shrink percentages for each of the three production scenarios[z].**

	Scenario A (Propagation to #1 to #3)	Scenario B (Propagation to Field to #3)	Scenario C (Propagation to #1 to #2 to #3)
Increase or decrease		**Added/reduced costs with varying labor rates**	
−10%	$1.7233	$1.8486	$1.9346
−5%	$1.7869	$1.9226	$2.0327
Baseline added cost per unit[z]	**$1.8505**	**$1.9966**	**$2.1307**
+5%	$1.9141	$2.0705	$2.2288
+10%	$1.9777	$2.1445	$2.3268
Increase or decrease		**Added/reduced costs with varying materials costs**	
−25%	$1.7520	$1.9142	$2.1025
−10%	$1.8111	$1.9636	$2.1194
−5%	$1.8308	$1.9801	$2.1251
Baseline added cost per unit	**$1.8505**	**$1.9966**	**$2.1307**
+5%	$1.8701	$2.0130	$2.1364
+10%	$1.8898	$2.0295	$2.1420
+25%	$1.9489	$2.0789	$2.1589
Increase or decrease		**Added costs with varying shrink percentages**	
Baseline added cost per unit	**$1.8505**	**$1.9966**	**$2.1307**
+5%	$1.9287	$2.1071	$2.2605
+10%	$2.0163	$2.2319	$2.4074
+15%	$2.1153	$2.3740	$2.5750
+20%	$2.2280	$2.5372	$2.7681
+25%	$2.3575	$2.7268	$2.9932

[z]The baseline added cost per unit represents the total added costs above and beyond costs incurred pre-boxwood blight for each of the 3 scenarios. The labor rate used for this study is then modified in ±5% increments to determine the effect on the baseline added cost per unit. Similarly, the costs for materials used in the study are also modified in ±5% increments to determine how sensitive the baseline added cost was to changes in input prices. Lastly, the shrink percentages were also adjusted in 5% increments to show the effect of losing a higher percentage of plants during production on the baseline added cost per unit.

liquid herbicide applications would be made annually to production areas using a boom sprayer and 45-hp tractor for 5.75 hrs·ha^{-1} (2.47 ac) per application. Hand weeding would average 1,203 labor hrs·ha^{-1} (2.47 ac) per year.

Fertility during propagation consisted of 3 kg·m^{-3} of 15N-3.5P-10K controlled-release fertilizer (CRF) incorporated during substrate preparation and weekly fertigation using 10N-0.87P-5.0K soluble fertilizer at 200 mg·L^{-1} (0.002 lbs/gal) of N. For the outdoor production phase, 8.3 kg·m^{-3} (0.52 lbs/ft^3) of 15N-3.5P-10K CRF would be incorporated in the substrate and surface applied at the beginning of the second growing season at 66 g (0.15 lb) per container. The 20% of plants marketed 6 months later would receive an additional 66 g of this product. Fertigation would be scheduled 7 times per year during which an average of 75 mg·L^{-1} N was added to the recycled water each irrigation cycle. Plants were mechanically pruned three times in each of the 1 and #3 container phases and was pruned by hand three more times.

Input materials, labor, and equipment use for Scenario B. Following 18 months' growth of the rooted cuttings in the 38-cell trays, liners would be transplanted in the field in the fall (Fig. 1). Controlled-release fertilizer (18N-2.6P-10K) would be incorporated in the propagation substrate at 3.9 kg·m^{-3}. Equipment-use time and labor assumed in the model for the field production phase to subsoil, plow, disk, apply lime and rototill during the fallow year field activities and in land preparation for planting were as previously published (Ingram 2012, Ingram 2013). The model assumed 39,604 liners would be planted per ha and 80% would be harvested for transplanting to #3 containers after 3 yrs in the field. A 74.6-kW tractor with transplanter would be used to transplant 7,000 plants per hour with a 15-member crew. A 10-hp tractor with a rototiller would be used to cultivate the fields twice annually at 3.09 hrs·ha^{-1}. Herbicide would be applied twice per year using an 18-kW tractor with spreader. Fertilizer (20N-2.2P-4.2K) would be banded in rows annually at 684 kg·ha^{-1} (610 lbs/ac) with an 18 kW-tractor and spreader. Field-grown plants would be irrigated 20 times per year using an overhead irrigation system powered by a 74.6-kW (100 hp) pump running 0.5 hrs per application. Plants would be pruned annually by hand at 1,333 plants per labor hr. Three hundred and seventy-five plants would be dug per labor hour and a 74.6-kW tractor and digger/shaker could harvest 3,200 per hr. Harvested plants would be transported 2,000/load using a large truck with a flat-bed trailer for 0.5 hrs and 0.5 hrs of a 35-hp forklift would be required.

Plants dug from the field in the fall of year 5 would be transplanted to #3 injection-molded containers and transported to gravel beds as described above. Fertilizer (18N-2.6P-10K) would be incorporated in the substrate at mixing at 5.7 kg·m^3 and top-dressed at 74 g (0.16 lbs) per #3 container annually, requiring 3.5 labor hrs per 10,000 plants. Overhead irrigations of 1.3 cm would be applied 196 times per year using four 74.6 kW pumps running 0.56 hrs per 10,000 containers. Irrigation management would require 47.5 hrs·ha^{-1} of labor and a pickup truck running 23.8 hrs. A tank mix of herbicides would each be applied once requiring 4.9 labor hrs·ha^{-1} (2.47 ac) and a 17.9-kW (24 hp) tractor and wagon for 2.5 hr·ha^{-1}. Insecticides would be applied in one spray annually using a

100-hp tractor with air blast sprayer for 1.24 hrs·ha^{-1} (2.47 ac). All plants would be pruned by hand once in this phase and 20% would be pruned twice due to being marketed at a later date.

Input materials, labor, and equipment use for Scenario C. Following 12 months' growth of the rooting cuttings in the 38-cell trays, liners would be transplanted to #1 injection-molded containers (0.272 kg) in the spring and grown for two years (Fig. 1). Substrate and fertilization in propagation was assumed to be the same as Scenario B. Controlled-release fertilizer (18N-2.6P-10K) would be incorporated in the substrate at 11.4 kg·m^{-3} and top-dressed at 17 g, 42 g and 74 g per #1, #2 and #3 containers annually; requiring 1 hr to fertilize 3,000 plants. Overhead irrigation of 1.3 cm would be applied 196 times per year, herbicides would be applied twice per year. Hand weeding and one insecticide application would be as described on an area basis for Scenario B for the #1, #2 and #3 container phases. Pruning of #1 container plants would consist of 1 mechanical pruning and three hand prunings. Plants in #2 containers would be hand pruned 3 times and 80% of plants in #3 containers would be pruned by hand once and the remaining 20% would be pruned twice.

Equipment use assumptions. Tractor power (1 hp = 0.746 kW) requirements were estimated for each function through nursery manager interviews. The portion of maximum tractor throttle and load for each operation was assumed to be: transporting plants on wagons, loading substrate components in mixer, 48.5-kW (48 hp) at 0.5 throttle and 0.5 load; pulling sprayers, and transporting other materials to the field, 17.9-kW (24 hp) tractor at 0.50 throttle and 0.50 load; spreading gravel on field beds, 40-kW (40 hp) tractor at 0.50 throttle and 0.50 load; loading bark in tumbler/screener, 55.9-kW (75 hp) loader at 0.85 throttle and 0.85 load; tumbler/screener for substrate preparation, 93.2-kW (125 hp) at 1.0 throttle and 1.0 load; and air-blast sprayer and herbicide boom sprayer, 100-hp tractor at 0.85 throttle and 0.85 load. The 5-hp gasoline powered sprayer was assumed to consume 1.25 L·hr^{-1} (0.33 gal). Gasoline-powered shearers were assumed to consume 0.63 L·hr^{-1} (0.17 gal). Electric motors for pumps and other equipment were assumed to use 0.746 kWh·hp^{-1}. A 50-hp diesel forklift at 0.50 throttle and 0.50 load would be used to load the truck for shipping.

Labor inputs. Labor requirements for each operation in the three scenarios were formulated by assuming existing BMPs would be utilized and validated through nursery manager interviews, with follow-up Delphi-method (Hsu and Sandford 2007) discussions. Labor is a significant portion of variable costs in each of the production scenarios. Equipment preparation and clean-up for each use would require 1.25 times more labor than the equipment operation hours, which is standard practice among economic engineering studies (Hall and Ingram 2014).

Cost calculations. An economic engineering approach was used to estimate variable costs for production system materials and activity as defined by each scenario. Fixed costs are highly variable between nurseries and were not included in this analysis, but typically range from 48 to 52% of total costs (www.yourmarketmetrics.com). Data regarding the Adverse Effect Wage Rate as determined by the U.S. Dept. of Labor and feedback received from advisory panel growers were used to set the hourly wage rate of $18.00. This wage also tends to act as a floor for non-migrant wage levels. Input material costs were obtained from price lists obtained from nursery industry wholesale distributors and manufacturers in 2023. Equipment costs per hour were updated to 2023 conditions from those reported in previous nursery cost studies (Ingram et al. 2016). The gasoline price used was the annual average reported by the U.S. Energy Information Administration for 2023.

Results and Discussion

The base scenario for each of the three production models (Fig. 1) was modified to include specific boxwood blight mitigation BMP's during nursery production as indicated in HRI (2020), LaMondia et al. (2023) and Dart et al. (2016). Each BMP identified by the Boxwood Blight Insight Group (BBIG) was evaluated as to the labor required, the equipment used, and whether any materials (inputs) were applied as part of each cultural practice.

The total costs of incorporating cultural practices to proactively mitigate boxwood blight for each of the three production systems are summarized in Table 1. Total variable costs for each of the scenarios were $8.57, $9.19, and $11.26 per plant for Scenarios A, B, and C, respectively. Each growing stage was summarized independently ranging from propagation, #1 containers, field stage (only for Scenario B), #2 containers (only for Scenario C), and #3 containers for all scenarios. Thus, as compared to pre-boxwood blight production costs, the added costs throughout the entire production cycle for each of the three scenarios, as compared to the pre-boxwood blight base scenarios, were $1.85, $1.99, and $2.13 higher per plant in #3 containers for each of the three scenarios, respectively. This equated to adding 26.0%, 27.8% and 23.3% in additional variable costs per plant for boxwood blight mitigating practices.

Interestingly, data obtained from cooperating growers indicate that the costs of scouting, training, and record-keeping went from pre-boxwood blight rates of $0.95, $1.14, and $0.95 per plant for Scenarios A, B, and C, respectively, to $1.90, $2.27, and $2.27 per #3 container plant when incorporating additional tasks for boxwood blight mitigation for each of the three scenarios respectively. Thus, the proactive control of boxwood blight is a time-intensive task that must be considered in costing procedures throughout the entire growth phase of the boxwood plants.

Sensitivity analyses. Table 2 summarizes how the costs of each scenario's production system are affected by labor rates, the costs of materials, and effects on plant shrinkage (e.g., culls, dumps, scrap). While increases of 5 or 10% may not seem like much, they can add significantly to per plant variable costs for plants in #3 containers. A mere 10% increase in wage rates increases incremental labor costs by $0.12, $0.15, and 0.19 per plant, for each of the scenarios respectively. Given that the Adverse Effect Wage Rate has increased 25 percent over the last 5 years (US DOL 2023), this can substantially add to the total cost of the boxwood plant. The added labor hours associated with boxwood-blight mitigation may reduce the profit margins per plant depending on whether the trends in output prices per plant more than offset the added costs per plant. A 25% increase in materials costs did not have as much of an effect on per-plant prices, with each scenario increasing $0.09, $0.08, and $0.03 respectively. Lastly, shrink can affect costs considerably, with each successive 5% increase in plant shrinkage costing approximately $0.07, $0.11, and $0.13 per plant for each plant for the three scenarios, respectively. So even a mild-to-moderate boxwood blight occurrence where shrink jumps to 25% translates to a loss of $0.50, $0.73, and $0.86 per #3 container boxwood plant under each of the three scenarios. Thus, the importance of this line of research in mitigating the likelihood of such losses.

The next phase of the boxwood blight project will involve measuring the added income resulting from increased yields and/or price premiums associated with higher quality crops; costs associated with additional land usage due to wider spacing used to aid airflow around the plants to aid in mitigating boxwood blight; and any income that may be lost when substituting one crop for another in the production system. These results will then be analyzed as to their implications for policymakers and stakeholders.

In conclusion, Boxwood blight, caused by the fungal pathogens *Calonectria pseudonaviculata* and *Calonectria henricotiae*, has had a significant impact on the nursery industry, particularly for those involved in the production and sale of boxwood plants (Buxus species). Boxwood is a popular ornamental shrub widely used in landscaping, and the disease has led to substantial economic losses for nurseries and growers, including: (1) plant losses from severe defoliation, stem cankers, and eventual death of infected boxwood plants. Nurseries may also experience significant losses of their salable boxwood stock (since some affected plants may not be completely dead but are not salable), leading to reduced inventory and revenue; (2) quarantine and regulatory measures to prevent the spread of the disease which many states and countries have implemented strict quarantine measures and regulations on the movement of boxwood plants and related materials should this disease be detected on a production facility. These measures can disrupt nursery operations, limit trade, and increase compliance costs; (3) treatment and management costs associated with controlling boxwood blight require the proactive application of fungicides, removal and destruction of infected plants, and implementation of strict sanitation measures. Many nurseries are now proactive on this and have a fungicide program in place to protect their crops from being affected. However, these measures are labor-intensive and costly for nurseries, affecting their profitability; (4) reduced demand and market losses as awareness of the disease increases, consumers and landscapers may become hesitant to purchase or plant boxwood, leading to reduced demand and market losses for nurseries specializing in these plants; (5) breeding and development efforts to develop boxwood cultivars with increased resistance or tolerance to boxwood blight, which can be a costly and time-consuming process; and (6) reputation and brand impact affecting nurseries known for their high-quality boxwood products. The presence of boxwood blight can damage their reputation and brand value, potentially leading to long-term consequences for their business. Overall, boxwood blight has posed significant challenges to the nursery industry, prompting changes in production practices, increased costs, and potential market shifts as nurseries adapt to mitigate the impacts of this destructive disease.

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