Estimated Nursery Liner Production Costs for Woody Ornamental Plant Stock

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SUMMARY. **Ornamental plant growers must be able to accurately assess production costs associated with woody liner stock to gain profit potential in a highly competitive industry. Fixed and variable cost inputs may not be intuitive or readily apparent to growers and may even differ between common types of production in the trade. To help liner producers identify profit-based price points for their woody ornamental liner stock, we modeled costs associated with producing familiar species and cultivars of a representative deciduous shade tree, a broadleaf evergreen, and a needle leaf evergreen liner. Production costs are projected down to individual plant units for each of the three most common liner production systems, including a field ground bed system, a polyhouse-covered (plant protection structure sheathed with one layer of 6-mil polyethylene film) ground bed system, and a polyhouse-covered container system. Production costs for individual plants varied due to the actual growing space available within each system. The field ground bed system offered greatest flexibility in crop planting density, with cost potentially distributed among the largest number of salable units. In addition to modeled costs, advantages and disadvantages of each liner cropping system are discussed.**

Mid-southern U.S. nursery growers may gain a competitive advantage if they can economically produce, rather than outsource, their own nursery liner stock plants. In part, these advantages accrue if growers can offer more consistent plant quality, greater convenience, and customer savings on high shipping costs of liners purchased from extra-regional producers or markets. Some percentage of on-site–grown liners may also be sold for profit, thus, growing liners on site may also present new market opportunities for nursery growers.

Several prior efforts have been undertaken to quantify cost estimates for various ornamental plant production systems in the southeastern U.S. (Hall et al., 1987; Hinson et al., 2007; Taylor et al., 1986, 1990). Specific to woody plant liner production in Tennessee, Dickerson et al. (1983) investigated production costs for three common nursery crop liners starting from rooted cuttings. While formulae developed in these studies remain beneficial to the industry, many of the actual costs estimated by earlier economic models need revision or no longer reflect the inputs used for current industry production practices. There is a need to update and modify these formulae to not only estimate current production costs, but to also make them available for growers to use quickly and effectively. The objectives of this study were to provide a more accurate model with cost projections that would be typical for three common growing systems used in southeastern U.S. liner production operations.

Materials and methods

The model liner nursery used for this study, which would likely be considered a medium-to-large nursery liner production operation, was set to encompass 10 acres with 1.5 acres consisting of facility structures and roads, and the remaining 8.5 acres used for production. Our model nursery employs 10 people, including four salaried employees (manager, assistant manager, plant propagator, and secretary) and six hourly workers. To better represent the variability that might occur between different methodologies of liner production, we modeled three of the most prominent liner production systems: 1) field ground bed system, 2) polyhouse-covered ground bed system, and 3) polyhouse-covered container system. Production areas within each system were established using 2000-ft^2 (20 ft wide × 100 ft long) crop production units. Each of the three systems was also compared by assessing costs to produce three different plants, which are representative of broader product categories. Model crops included red maple (*Acer rubrum*), 'Foster' holly (*Ilex* ×*attenuata*), and giant (or western) arborvitae (*Thuja plicata* 'Green Giant'), which can be classified as deciduous shade tree, broadleaf evergreen, and needle leaf evergreen, respectively. Where critical parameters for each cost category are described below, supplemental tables are also available upon request from the corresponding author. These include specific accounting for additional capital requirements and annual fixed costs, as well as itemization and annual equipment-specific operating cost details related to each of the three production systems (data not shown).

GROWING SYSTEM DESCRIPTIONS. Maintained within the field ground bed system are three 567-ft^2 (5.67 ft wide × 100 ft long) growing areas and a 1.5-ft-wide path between each growing area, to yield an actual growing area of 1701 ft^2. The polyhouse-covered ground bed system and polyhouse-covered container system growing blocks are covered by a

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft^2	m^2	10.7639
3.7854	gal	L	0.2642
0.7457	horsepower	kW	1.3410
2.54	inch(es)	cm	0.3937
0.0254	mil	mm	39.3701

cold-frame polyhouse. The growing blocks in these systems are split into two 693-ft^2 (7 ft wide × 99 ft long) areas by a 5-ft-wide path with a 0.5-ft-wide buffer strip that surrounds the perimeter of the growing area to ensure that plants are not shaded by crops in adjacent blocks. Thus, the two 693-ft^2 growing areas in these systems each yield total growing areas of 1386 ft^2.

Determination of capital requirements and fixed costs. Capital inputs (including costs of land, improvements, buildings, and equipment) for each growing system were determined by using the consumer price index [CPI (U.S. Department of Labor, 2008)] to deflate older cost estimates to current day costs, thus accounting for inflation.

Fixed costs, which are expenses that do not vary with the level of production, include depreciation, interest, repairs, insurance, taxes, and general overhead. Depreciation is a non-cash cost that is determined formulaically by using the straight-line method (Badenhop, 1985). General overhead and repairs were estimated using the CPI to adjust costs in 1980 to current cost estimates. Insurance and taxes were assessed as costing an additional 20% as calculated from the original cost of the item (Badenhop, 1985). Interest expenses were estimated as costing an additional 7% of the overall item value calculated when initial cost and salvage value are averaged (Badenhop, 1985). For convenience, dollar amounts reported in text that exceed $100 are rounded to the nearest whole dollar.

To allocate total annual fixed costs relative to actual growing areas, totals for each system were divided into the area of square feet in production (8.5 acres = 370,260 ft^2) yielding fixed costs per square foot. Fixed cost per square foot was then multiplied by square footage within a growing area, 1701 ft^2 for the field ground bed system, and 1386 ft^2 for the polyhouse-covered ground bed and container systems, to obtain total fixed cost per growing area. Once total fixed costs were determined, that amount was divided by 370,260 ft^2, equivalent to 8.5 acres, to determine cost per square foot. We then calculated the cost per growing area for each production system by multiplying costs per square foot by the actual amount of growing space available. Finally, to assess fixed costs on a per plant unit basis, total fixed costs per growing area were divided by the projected number of plants capable of being produced within the model growing area.

Determination of variable costs. Variable costs for production inputs (e.g., chemical and fertilizer applications, hand planting or sticking cuttings, harvesting, etc.) were computed using a modified Delphi method (Skulmoski et al., 2007) and projected for one growing area per system per year. For field ground bed and polyhouse-covered ground bed systems, variable costs associated with rooting and sticking cuttings were determined by grouping hormone costs and the labor necessary to treat 22,222 cuttings each of ‘Foster’ holly and giant arborvitae. Costs for the polyhouse-covered container system were based on establishing 13,266 cuttings of both crops. Costs of rooting hormone application were estimated using liquid rooting concentrate (Dip’N Grow, Clackamas, OR) per the semihardwood label recommendation rate with a 5-s immersion of bundles of 25 cuttings. Red maple plant production was calculated using a seed count of about 5000 seeds/lb yielding a 72% germination rate (Farmer and Goelz, 1984). Propagation shrinkage for crops was held constant with a 10% loss projection, which conversations with nursery propagators suggested was reasonable for these crops (A.H. Jeffers, unpublished data). Final crop production was expected to yield about 20,000 plant units in field ground bed and polyhouse-covered ground bed systems, and 11,939 plants in the polyhouse-covered container system.

While actual management actions that must be performed differ between growing systems and by plant species, costs were grouped within general category (e.g., preparation of growing area/medium, planting and rooting, chemical applications, misting and irrigating, overwintering, root pruning, harvesting, and storage). Media preparation for the polyhouse-covered container system included initial cost of substrate, fertilizers, fire ant (*Solenopsis* spp.) treatments, labor, and mixer operating costs, and was modeled identically for all three crops. All relevant management actions were calculated on an annual basis for one 20-ft-wide by 100-ft-long growing area for each production system [adapted from Hall et al. (1987) and Hinson et al. (2007)].

Typical payroll costs were calculated after conversations with Tennessee growers and after assessing industry wage and salary survey data (American Nurseryman, 2008). Based on these surveys, gross monthly pay rates were set for a manager ($5200), an assistant manager ($4800), a plant propagator ($4600), and an administrative assistant ($2579). Nursery worker monthly gross pay of $1360 for six employees reflected a wage rate of $8.50/h that was typical for the region. All payroll withholdings and taxes were determined using current U.S. Internal Revenue Service rates (U.S. Internal Revenue Service, 2009). For example, Federal Insurance Contribution Act (FICA) taxes were determined by multiplying employee gross pay by 6.2%, Medicare taxes were calculated by multiplying employee gross pay by 1.45%, and Federal income taxes were determined by multiplying employee gross pay by 14%.

Nursery equipment operating costs were calculated for each type of equipment, including fuel-driven equipment, non-powered equipment, and electricity-driven equipment. Hourly operating costs for fuel-driven equipment were determined by adding fuel costs per hour to lubrication costs per hour and hourly projected labor (maintenance) cost. Fuel costs per hour projections were determined by multiplying a contemporary estimated fuel prices (e.g., $3.25/gal for gasoline and $3.75/gal for diesel fuel) by the maximum power take off (PTO) horsepower of the machine, then multiplying that value by either 0.044 (for diesel engines) or 0.06 (for gasoline engines) (Edwards, 2009; Lazarus, 2009). Lubrication costs were determined by multiplying the hourly fuel cost by 0.15 (Pfleuger, 2005). Labor costs were determined by multiplying the hourly labor wage rate by 1.1 to account for equipment travel and setup. These values were then summed, yielding the total equipment operating costs per hour for fuel-driven equipment. To assess total annual operating costs, hourly equipment cost was multiplied by the projected number of hours of annual use (Hall et al., 1987; Pfleuger, 2005).

For non-powered equipment, the number of hours of projected annual use was multiplied by the expected number of years of useful life. This value was then divided by the cost of new equipment to yield an hourly operating cost estimate for each item. Similarly, hours of projected annual use was multiplied by hourly operating costs to yield total annual operating costs (Hall et al., 1987; Pfleuger, 2005).

Electric-powered equipment costs per hour in this study for operating electricity-driven equipment were calculated using an average kilowatt hour costs for the southeastern U.S. and multiplying kilowatt hours of projected equipment use by the average commercial cost of electricity as \$0.104/kWh (U.S. Department of Energy, 2008). Kilowatt hour usage by equipment was determined by multiplying the horse power of equipment by 0.746 kW, where 1 h of electricity consumes the equivalent 0.746 kW. Equipment cost per hour was then multiplied by number of hours of projected annual use yielding total annual operating cost (Hall et al., 1987; Pfleuger, 2005).

TOTAL COST AND COST PER PLANT DETERMINATIONS. Total annual production costs were determined by summing together the total annual fixed costs per growing area and the total annual variable costs. After determining the total annual production costs per 2000 ft^2 (20-ft-wide by 100-ft-long growing area), that value was then divided by the number of square feet in actual crop production within each production system, thus providing plant production costs on a square foot basis.

To determine total production cost per plant, total cost per square foot was divided by the number of plants per square foot as specified by planting density within the 1701-ft^2 model field ground bed system. For the polyhouse-covered container systems, the total annual production cost of the growing area was divided by the total number of plants that could be grown within 1386-ft^2 production areas.

To determine if cultural manipulations during nursery liner production can be cost effective on a per plant basis, we assessed cost inputs for bed planting densities of 128, 64, and 32 stems/m^2 [after Shultz and Thompson, 1996 (equivalent to 11.9, 5.9, and 3.0 stems/ft^2, respectively) and compared these values to a typical commercial nursery liner bed planting density of about 36 stems/ft^2 (387.5 stems/m^2). Costs per plant in the polyhouse-covered container system were determined based on plants grown in 4-inch-diameter rose (band) pots.

Finally, levels of each independent cost variable, as well as actual crop losses, are expected to differ slightly between nearly every production system, growing season, and individual grower's operation. In addition, growers often incorporate multiple production systems within a single nursery. For these reasons, we did not attempt to analyze our data statistically. Rather, our long-term goal is a means of uniformly itemizing cost inputs using hypothetical production models, in spreadsheet form, which can be manipulated by growers to more accurately reflect changing prices, propagation outputs, and presence, level, or absence of individual component inputs.

Results and discussion

CAPITAL REQUIREMENTS AND FIXED COSTS. An initial land and improvement investment of \$376,086 was required for each of the three growing systems, which was about 42% of total nursery capital requirements. Additional buildings and facilities cost between 26% and 30% of total growing system investment (Table 1). The polyhouse-covered ground bed system required the most capital for buildings (\$286,840), followed by the field ground bed system (\$284,711), while buildings associated with the polyhouse-covered container system were the cheapest (\$232,995). In all, the field ground bed system was the most expensive to establish, with total costs of about \$900,000. The costs of polyhouse-covered ground bed and container system establishment were above \$870,000, differing by only about \$5,600 (Table 1). However, the variance between the polyhouse-covered ground bed and the container system is somewhat offset by combined costs of the media mixer, hopper, and a flat or pot filler for the container system. Capital investment projections vary if nurseries simply expanding current operations have other sources of revenue. Investment costs will also be reduced if growers lease or purchase used equipment. A nursery owner should consider consulting a tax preparer or accountant to ascertain potential tax credits or penalties that may be incurred from purchasing used equipment.

At \$236,028, general overhead related to administrative pay, utilities, and advertising comprised about 69% of total annual fixed costs for all three growing systems (Table 1). General overhead can include additional insurance policies or benefits. Also within total system fixed costs (Table 1), annual depreciation of land improvements, buildings, and equipment used for each of the three growing systems made up about 15% of the total annual fixed costs (data not shown). Though depreciation is a non-cash expense, it is still recognized as a line-item expense (Badenhop, 1985; Scarborough and Zimmerer, 2006). Similarly, annual interest expenses were about 10% of total annual fixed costs for each of the three growing systems. Interest expenses in this study were calculated by adapting previous research formula (Badenhop, 1985) and adjusting to a 7% interest rate. Insurance and tax expenses only comprised about 5% of the total annual fixed costs, regardless of growing system. In sum, the field ground bed system had the highest fixed costs per square foot of growing area at \$0.9206 (or \$1567 per 1701 ft^2), while the fixed costs for the polyhouse-covered ground bed and container system square feet were \$0.9114 and \$0.0107, respectively (or just over \$1260 per 1386-ft^2 growing area) (Table 1).

PAYROLL COSTS. Payroll rates, which were held constant between the respective growing systems to facilitate equipment operating and variable cost calculations, yielded total monthly payroll costs of \$27,278, or \$327,332 annually. These costs included \$7424 in monthly FICA, Medicare, and income tax withholdings. When determining Medicare and FICA withholdings, the employer must pay the amount directly withheld from the employee and an employer equivalent match to that amount. The employer is not responsible for matching the employee's federal income tax withholding. Because Tennessee does not assess income tax except on dividends and interest, payroll costs for

Table 1. Comparisons among capital investments, system total fixed costs, and production fixed costs per square foot and per growing area of three contemporary liner-growing systems.

Growing system	Total capital investment ($)	Total system fixed cost ($)[z]	Actual system growing space (ft^2)[y]	Fixed production cost ($\$/ft^2$)[x]	Fixed cost per growing area ($\$/ft^2$)[w]
Field ground bed					
Land and improvements	376,085.67	34,588.00	1,701	0.0934	158.87
Buildings	284,710.50	37,919.32	1,701	0.1024	174.18
Equipment[v]	239,118.40	32,319.82	1,701	0.0873	148.50
General overhead	—	236,027.78	1,701	0.6375	1,084.39
Total	899,914.57	340,854.92	1,701	0.9206	1,565.94
Polyhouse-covered[u] ground bed					
Land and improvements	376,085.67	34,588.00	1,386	0.0934	129.45
Buildings[t]	286,840.34	38,235.61	1,386	0.1033	143.17
Equipment	214,454.06	28,572.66	1,386	0.0772	107.00
General overhead	—	236,027.78	1,386	0.6375	883.58
Total	877,380.07	337,424.05	1,386	0.9114	1,263.20
Polyhouse-covered container					
Land and improvements	376,085.67	34,588.00	1,386	0.0934	129.45
Buildings[t,s]	232,995.34	32,662.65	1,386	0.0882	122.24
Equipment[r]	262,704.39	33,918.66	1,386	0.0916	126.96
General overhead	—	236,027.78	1,386	0.6375	883.58
Total	871,785.40	337,193.69	1,386	0.9107	1,262.23

[z]Total system fixed costs include annual depreciation (based on a salvage value of 10% of initial investment cost), interest, insurance, and taxes.
[y]1 ft^2 = 0.3048 m^2.
[x]Fixed production cost per nursery square foot ($1.00/$ft^2$ = $3.2808/$m^2$) was computed by dividing the total system fixed costs by the number of total production-ready square feet in the nursery [8.5 acres × 43,560 ft^2/acre (3.44 ha × 10,000 m^2/ha)].
[w]Cost per growing area was computed by multiplying the fixed production cost per nursery square foot by the amount of actual system growing space.
[v]Field ground bed system equipment differs from polyhouse-covered systems by typically requiring additional 50-horsepower (37.3 kW) tractor (estimated cost = $23,423.76).
[u]Plant protection structure sheathed with one layer of 6-mil (0.15-mm-thick) polyethylene film.
[t]Building costs for polyhouse-covered systems include polyhouse structures, classified within the spreadsheet as "buildings" (estimated cost = $2,129.84).
[s]Building costs for polyhouse-covered container system differs from field ground bed and polyhouse-covered ground bed systems by typically excluding the cost of the liner storage cooler (estimated cost = $53,845).
[r]Equipment costs for polyhouse-covered container system differs from field ground bed and polyhouse-covered ground bed systems by typically requiring additional purchase of a pot/flat filler, soilless substrate hopper, and media mixer (estimated cost = $53,136).

these projections do not include state income taxes or withholdings. Our base wage of $8.50 per hour was lower than the $9.15 Adverse Effect Wage Rate for Tennessee (AEWR), which must be paid if employing workers on H2A and H2B visas (U.S. Department of Labor, 2008), but represents a consensus wage among nurseries consulted for the study.

Equipment operating costs. Regardless of liner production system, fuel-driven equipment costs are responsible for the majority of annual equipment operating costs. Because current gasoline and diesel fuel prices are fluctuating drastically, we calculated these costs using fuel prices of $3.25/gal for regular unleaded gasoline and $3.75/gal for diesel fuel. At about $62,395, the highest total annual fuel-driven equipment costs were incurred for the field ground bed system, with both polyhouse-covered systems having about $9600 less in annual fuel consumption costs. Non-power equipment and electrically driven equipment were operated at a fraction of the cost of fuel-driven equipment, ranging in annual expenditures of about $2800 to $3700 for non-power equipment and about $4750 to $6400 for electrically driven equipment (Table 2). Differences are attributed to asset specificity (the amount and type of equipment required by each system). For example, the field ground bed and polyhouse-covered ground bed systems required a fertilizer spreader and a u-blade, but these were not needed for the container system. Similarly, the polyhouse-covered container system had higher electrical use charges associated with the media mixer, hopper, and flat/pot filler that were specific to this system (Table 2).

Total variable costs. Variable cost trends were largely consistent across production systems, with the polyhouse-covered ground bed system cheapest to use (Table 3), followed by the field ground bed production system (Table 4). Overall, the polyhouse-covered container system was the most expensive production system (Table 5), with total production costs per actual growing area about $5000 more than the polyhouse-covered ground bed system and $3500 more than the field ground bed system. Production cost differences have been summarized to facilitate system- and crop-based comparisons (Table 6).

Nursery liner production costs are expected to differ not just by production system, but also across different crop types. To account for this variability, we modeled costs within broad crop production categories: red maple as a representative deciduous shade tree, 'Foster' holly as a representative broadleaf evergreen, and giant arborvitae as a representative needle leaf evergreen plant. Although fixed costs within each growing system can generally be held constant for production of many plant species, variable costs will differ, for example, based on crop management, production techniques, and handling requirements.

Regardless of production system, red maple liners were cheapest to produce, incurring between $1100 and $1800 less than total annual variable costs associated with growing 'Foster' holly and giant arborvitae

Table 2. Comparison of annual equipment operating costs of three 10-acre (4.0 ha) nursery liner-growing systems.

Growing system	Total annual operating cost ($)[z]	Hourly cost ($)
Field ground bed system		
Fuel-driven equipment	62,394.57	124.90
Non-power equipment	3,483.86	4.58
Electrically powered equipment	4,750.66	1.41
Total annual costs ($)	70,629.08	130.89
Polyhouse-covered[y] ground bed system		
Fuel-driven equipment	52,827.76	102.17
Non-power equipment	3,715.50	5.27
Electrically powered equipment	4,750.66	1.41
Total annual costs ($)	61,293.92	108.85
Polyhouse-covered container system		
Fuel-driven equipment	52,827.76	102.17
Non-power equipment	2,763.84	2.03
Electrically powered equipment	6,400.12	2.03
Total annual costs ($)	61,991.72	106.23

[z]Total annual operating cost derived as sum of (fuel cost + lubrication + labor costs) multiplied by estimated annual use of each piece of related equipment where: fuel cost per hour = maximum power take off (PTO) horsepower × current fuel cost per gallon × 0.044 (diesel) [or 0.06 (gasoline)]; labor (travel and maintenance) = hourly wage rate × 1.1; and lubrication cost = 0.15 × fuel cost per hour [Note: diesel fuel price estimate = \$3.75/gal (\$0.991/L) and gasoline = \$3.25/gal (\$0.859/L)]. Additional specific details about annual hourly equipment use estimates are available from the corresponding author upon request.
[y]Plant protection structure sheathed with one layer of 6-mil (0.15-mm-thick) polyethylene film.

Table 3. Summary of the total annual production costs of a 10-acre (4.0 ha) liner nursery using the polyhouse-covered[z] ground bed growing system for one 20-ft-wide by 100-ft-long (6.1 × 30.5 m) growing area with 1386 ft^2 (128.8 m^2) of actual growing space.

Item	Red maple	'Foster' holly	Giant arborvitae
Fixed costs			
Total annual cost ($)	337,424.05	337,424.05	337,424.05
Fixed cost ($/ft^2)[y]	0.9114	0.9114	0.9114
Total growing area cost ($)	1,263.20	1,263.20	1,263.20
Variable costs[x]			
Pre-plant herbicide application ($)	33.08	33.08	33.08
Tillage ($)	56.40	56.40	56.40
Fertilizer application ($)	23.82	23.82	23.82
Stratification ($)	368.43	—	—
Rooting ($)	—	56.40	56.40
Planting/sticking ($)	36.60	2,135.63	2,191.19
Postemergent herbicide application ($)	910.07	910.07	910.07
Insecticide application ($)	246.87	246.87	286.97
Fungicide application ($)	304.07	304.07	304.07
Misting ($)	767.80	767.80	767.80
Irrigation ($)	8,654.12	8,654.12	8,654.12
Undercutting ($)	80.18	80.18	80.18
Harvesting ($)	95.15	95.15	95.15
Transportation from field ($)	13.25	13.25	13.25
Cooler storage ($)	1,203.32	1,203.32	1,203.32
Total variable cost ($)	12,793.16	14,580.16	14,675.82
Total production cost ($ per growing area):	14,056.36	15,843.36	15,939.02

[z]Plant protection structure sheathed with one layer of 6-mil (0.15-mm-thick) polyethylene film.
[y]Total fixed cost per square foot within system is computed by taking the total annual fixed cost and dividing it by the number of acres in production converted into square feet [thus, 8.5 acres × 43,560 ft^2/acre (3.44 ha × 10,000 m^2/ha)]; \$1.00/ft^2 = \$3.2808/m^2.
[x]Derived from Delphi method, consumer price index (CPI), and formulaic methods. Adapted from Hinson et al. (2007) and Hall et al. (1987).

liners (Tables 3–5). Differences are principally due to costs associated with labor for rooting cuttings and planting 'Foster' holly and giant arborvitae liners. Note that for all systems, variable costs for planting and sticking cuttings are highest in the year of initiation, due to costs of establishing 'Foster' holly and arborvitae stock blocks (Tables 3–5). Planting and sticking costs for these crops would be reduced by about 66% in subsequent years (data not shown). We also caution readers that cost projections for red maple liners grown from seed do not include subsequent costs for grafting associated with many clonal cultivars.

Chemical application costs for the fungicide mefenoxam (Subdue MAXX®; Novartis Crop Protection, Greensboro, NC) were similar for all crops, but insecticide use differed because imidacloprid (Merit®; Bayer Environmental Science, Research Triangle Park, NC) was used for red maple and 'Foster' holly, while the miticide abamectin (Avid®; Syngenta Crop Protection, Greensboro, NC) was used for managing mites on giant arborvitae (Table 3).

TOTAL PRODUCTION COSTS AND PRODUCTION COSTS PER PLANT. Costs incurred by growers for each plant unit produced will depend on planting or container densities within available production space. In short, as bed planting density decreases, there is a corresponding increase in cost per plant, assuming that shrinkage rates remain constant. Conversely, by decreasing planting densities, a grower has fewer plants to sell. These effects are most apparent from our field ground bed and polyhouse-covered ground bed models.

At typical commercial planting densities of about 36 stems/ft^2, red maple liners were the least expensive crop to produce. Unit costs for red maples grown in field ground bed and polyhouse-covered ground bed systems were \$0.25 and \$0.28, respectively, yielding about 61,236 units in the 1701 ft^2 of field ground space versus 49,890 units in the 1386 ft^2 of polyhouse-covered ground bed production space (Table 7). Per plant, 'Foster' holly and giant arborvitae liners cost more to produce than red maples, but production costs varied little between these two plant types: about \$0.28 each in the field ground

Table 4. Summary of the total annual production costs of a 10-acre (4.0 ha) liner nursery using the field-ground bed growing system for one 20-ft-wide by 100-ft-long (6.1 × 30.5 m) growing area with 1701 ft² (158.0 m²) of actual growing space.

Item	Red maple	'Foster' holly	Giant arborvitae
Fixed costs			
Total annual cost ($)	340,854.92	340,854.92	340,854.92
Fixed cost per unit area ($/ft²)[z]	0.9206	0.9206	0.9206
Total growing area cost ($)	1,565.94	1,565.94	1,565.94
Variable costs[y]			
Pre-plant herbicide application ($)	33.08	33.08	33.08
Tillage ($)	60.95	60.95	60.95
Fertilizer application ($)	24.75	24.75	24.75
Stratification ($)	416.96	—	—
Rooting ($)	—	58.95	58.95
Planting/sticking ($)	13.73	1,975.42	1,966.48
Postemergent herbicide application ($)	910.07	910.07	910.07
Insecticide application ($)	246.87	246.87	286.97
Fungicide application ($)	314.65	314.65	314.65
Misting ($)	1,178.44	1,178.44	1,178.44
Irrigation ($)	8,654.12	8,654.12	8,654.12
Overwintering ($)	661.70	661.70	661.70
Undercutting ($)	80.18	80.18	80.18
Harvesting ($)	95.15	95.15	95.15
Transportation from field ($)	13.25	13.25	13.25
Cooler storage ($)	1,212.84	1,212.84	1,212.84
Total variable cost ($)	13,916.74	15,461.48	15,551.58
Total production cost ($ per growing area):	15,482.68	17,027.42	17,117.52

[z]Total fixed cost per square foot within system is computed by taking the total annual fixed cost and dividing it by the number of acres in production converted into square feet [thus, 8.5 acres × 43,560 ft²/acre (3.44 ha × 10,000 m²/ha)]; $1.00/ft² = $3.2808/m².
[y]Derived from Delphi method, consumer price index (CPI), and formulaic methods. Adapted from Hinson et al. (2007) and Hall et al. (1987).

Table 5. Summary of the total annual production costs of a 10-acre (4.0 ha) liner nursery using the polyhouse-covered[z] container system for one 20-ft-wide by 100-ft-long (6.1 × 30.5 m) growing area with 1386 ft² (128.8 m²) of actual growing space.

Item	Red maple	'Foster' holly	Giant arborvitae
Fixed costs			
Total annual cost ($)	337,196.39	337,196.39	337,196.39
Fixed cost per ($/ft²)[y]	0.9107	0.9107	0.9107
Total growing area cost ($)	1,262.23	1,262.23	1,262.23
Variable costs[x]			
Media preparation ($)	5,544.60	5,544.60	5,544.60
Filling containers ($)	803.91	803.91	803.91
Planting/rooting/sticking ($)	220.40	1,280.39	1,313.56
Postemergent herbicide application ($)	910.07	910.07	910.07
Insecticide application ($)	246.87	246.87	286.97
Fungicide application ($)	304.07	304.07	304.07
Misting ($)	1,178.44	1,178.44	1,178.44
Irrigation ($)	8,654.12	8,654.12	8,654.12
Harvesting ($)	96.08	96.08	96.08
Transportation from field ($)	185.47	185.47	185.47
Total variable cost ($)	18,144.03	19,204.02	19,277.29
Total production cost ($ per growing area):	19,406.26	20,466.25	20,539.52

[z]Plant protection structure sheathed with one layer of 6-mil (0.15-mm-thick) polyethylene film.
[y]Total fixed cost per square foot within system is computed by taking the total annual fixed cost and dividing it by the number of acres in production converted into square feet [thus, 8.5 acres × 43,560 ft²/acre (3.44 ha × 10,000 m²/ha)]; $1.00/ft² = $3.2808/m².
[x]Derived from Delphi method, consumer price index (CPI), and formulaic methods. Adapted from Hinson et al. (2007) and Hall et al. (1987).

bed system and about $0.32 per plant in the polyhouse-covered ground bed system (Table 7). By contrast, per plant costs were much higher in the polyhouse-covered container system, regardless of crop type (Table 7). In large part, cost increases in the polyhouse-covered container system are attributed to use of 4-inch-diameter rose (band) pots and 18-cell trays, which fixes possible plant counts at 11,939 units per 1386 ft² of growing space.

At planting densities of 11.9 stems/ft², red maple liners were about $0.08 cheaper to produce than 'Foster' holly and arborvitae liners in the field ground bed system, and $0.11 cheaper in the polyhouse-covered ground bed system (Table 7). These trends are consistent at planting densities of 5.9 and 3.0 stems/ft^2, but well-spaced liner production dramatically increases unit costs on a per plant basis (Table 7). Furthermore, at higher planting densities, liners may not have sufficient room to develop high-quality root architecture (Jeffers et al., 2009; Schultz and Thompson, 1996).

First-order lateral roots (FOLR), which are roots greater than 1 mm in diameter that emerge 30 mm below the root collar, often provide better field survivability and plant vigor after transplanting (Kormanik et al., 1998; Schultz and Thompson, 1996). A recent survey identified higher FOLR number, followed by uniform liner height and canopy density, as the most important attributes influencing bare root nursery liner preference, as measures of plant quality (Jeffers et al., 2009). Indeed, by culturally lowering hardwood seedling planting densities in propagation beds, higher quality root development and an increase in FOLR number often results (Schultz and Thompson, 1996). There may be incentives for quality-conscious liner producers to decrease planting densities, if the resulting nursery liners earn price premiums that exceed the added production costs for each plant unit.

Table 6. Summary of production costs for three contemporary nursery liner growing systems in which growing systems are assumed to occur on separate 10-acre (4.0 ha) liner nurseries (values in italics help illustrate system differences).

Growing system	Red maple	'Foster' holly	Giant arborvitae
Field ground bed			
Total annual fixed cost ($)	340,854.92	340,854.92	340,854.92
Fixed cost ($/$ft^2$)[z]	0.9206	0.9206	0.9206
Fixed growing area cost ($)[y,x]	1,565.94	1,565.94	1,565.94
Total variable cost ($)	*13,916.74*	*15,461.48*	*15,551.58*
Total growing area cost ($)	*15,482.68*	*17,027.42*	*17,117.52*
Polyhouse-covered[w] ground bed			
Total annual fixed cost ($)	337,424.05	337,424.05	337,424.05
Fixed cost/unit area ($/$ft^2$)	0.9114	0.9114	0.9114
Fixed growing area cost ($)[y,v]	1,263.20	1,263.20	1,263.20
Total variable cost ($)	*12,793.16*	*14,580.16*	*14,675.82*
Total growing area cost ($)	*14,056.36*	*15,843.35*	*15,939.01*
Polyhouse-covered container			
Total annual fixed cost ($)	337,196.39	337,196.39	337,196.39
Fixed cost ($/$ft^2$)	0.9107	0.9107	0.9107
Fixed growing area cost ($)[y,v]	1,262.23	1,262.23	1,262.23
Total variable cost ($)	*18,144.03*	*19,204.02*	*19,277.29*
Total growing area cost ($)	*19,406.26*	*20,466.25*	*20,539.52*

[z]Total fixed cost per square foot within system is computed by taking the total annual fixed cost and dividing it by the number of acres in production converted into square feet [thus, 8.5 acres × 43,560 ft^2/acre (3.44 ha × 10,000 m^2/ha)]; $1.00/$ft^2$ = $3.2808/$m^2$.
[y]Fixed growing area cost = fixed cost per square foot × actual square feet within each specific growing system; 1 ft^2 = 0.3048 m^2.
[x]Total growing area within the 2000-ft^2 (185.8 m^2) system block is 1701 ft^2 (158.0 m^2).
[w]Plant protection structure sheathed with one layer of 6-mil (0.15-mm-thick) polyethylene film.
[v]Total growing area within the 2000-ft^2 system block is 1386 ft^2 (128.8 m^2).

Conclusions

Costs associated with the polyhouse-covered ground bed differed from the field ground bed system, primarily as a result of the amount

Table 7. Per plant production costs in three different 10-acre (4.0 ha) nursery liner growing systems with varying liner planting densities (after Schultz and Thompson, 1996).

Growing system plant type	Plants (no.)	Production cost ($/plant)[z]	Plants (no.)	Production cost ($/plant)	Plants (no.)	Production cost ($/plant)	Plants (no.)	Production cost ($/plant)
	36 plants/ft^2[y] (387.5 plants/m^2)		11.9 plants/ft^2 (128 plants/m^2)		5.9 plants/ft (64 plants/m^2)		3.0 plants/ft^2 (32 plants/m^2)	
Field ground bed[x]								
Red maple	61,236	0.2528	20,242	0.7649	10,036	1.5427	5,103	3.0340
'Foster' holly	61,236	0.2781	20,242	0.8412	10,036	1.6966	5,103	3.3367
Giant arborvitae	61,236	0.2795	20,242	0.8456	10,036	1.7056	5,103	3.3544
Polyhouse-covered[w] ground bed[v]								
Red maple	49,890	0.2817	16,493	0.8523	8,177	1.7190	4,158	3.3806
'Foster' holly	49,890	0.3176	16,493	0.9606	8,177	1.9376	4,158	3.3813
Giant arborvitae	49,890	0.3195	16,493	0.9664	8,177	1.9493	4,158	3.3833
Polyhouse-covered container[v]								
Red maple				11,939[u]	1.6255			
'Foster' holly				11,939	1.7142			
Giant arborvitae				11,939	1.7204			

[z]Production costs per plant were calculated for each production system by dividing total production costs per growing area (Tables 3–5) by the total number of plants produced at the stated planting density.
[y]Typical commercial nursery liner planting density is about 36 plants/ft^2.
[x]1701 ft^2 (158.0 m^2) of growing space within 2000-ft^2 (185.8 m^2) block.
[w]Plant protection structure sheathed with a single layer of 6-mil (0.15-mm-thick) polyethylene film.
[v]1386 ft^2 (128.8 m^2) of growing space within 2000-ft^2 block.
[u]Within a polyhouse-covered container system, the use of 4-inch-diameter (10.2 cm) rose (band) pots in 18-cell trays [1.89 ft^2 (0.176 m^2) used per tray] results in a fixed number of plants within available production area, regardless of plant type.

of actual growing space available to produce plants. Equipment for the polyhouse-covered ground bed and the field ground bed systems were similar, but the amount of space dedicated to 5-ft-wide aisle and buffer strips on the sides of the production area reduced the actual amount of growing space available within the 2000-ft^2 block.

Despite needing more capital requirements for equipment and a cooler for liner storage, the field ground bed system requires the least input in facilities and is also one of the easiest systems to establish. Field ground bed systems also permit the greatest flexibility in crop planting densities and can facilitate production of the greatest number of plants per square foot. In turn, costs of production are distributed over a larger number of salable units. A disadvantage of the field ground bed system is full environmental exposure with consequent dependence on favorable weather for management actions like crop harvesting. If soils in fields are too wet following rainfall for example, planting, maintenance, and harvesting may be delayed or soil structure and worker safety may be compromised.

Polyhouse-covered ground bed systems offer advantages similar to field ground bed systems, including variable planting densities, and add additional crop protection as overwintering protection and maintenance beneath a polyhouse cover. As a consequence, the polyhouse-covered ground bed system can offer environmental benefits allowing good root development with addition of a controlled environment that increases crop growth rate. In theory, a grower using polyhouse-covered ground beds can produce a salable crop in less time than the same crop grown in a field ground bed system. A major disadvantage of this system is a reduction in actual production space. For highest efficiency, a center aisle is often left wide enough to allow passage of tractors and other equipment, thus reducing available growing space. Although similar to the polyhouse-covered ground bed system, the polyhouse-covered container system is not specifically dependant on bed density and is instead constrained by the size and style of container in which plants are grown. Costs also vary if the grower stacks containers pot tight and for how long during the production cycle.

Although each of the liner production systems we modeled have different input and cost parameters, growers will continue to adapt and modify the basic framework to meet specific needs and to capitalize on each system's independent advantages. Indeed, many growers use two or more of these systems simultaneously, depending on past crop productivity and experience. We expect contemporary modular analyses like these, with detailed costs projected per plant unit and assessed per square foot on actual growing area, to be particularly useful for growers who are interested in better predicting costs and consequences before expanding and adapting their individual operations.

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