Production Costs of Field-grown *Cercis canadensis* L. ‘Forest Pansy’ Identified during Life Cycle Assessment Analysis

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Abstract. University researchers have recently quantified the value of carbon sequestration provided by landscape trees (Ingram, 2012, 2013). However, no study to date has captured the economic costs of component horticultural systems while conducting a life cycle assessment of any green industry product. This study attempts to fill that void. The nursery production system modeled in this study was a field-grown, 5-cm (2-in) caliper *Cercis canadensis* ‘Forest Pansy’ in the Lower Midwest. Partial budgeting modeling procedures were also used to measure the sensitivity of related costs and potential benefits associated with short-run changes in cultural practices in the production systems analyzed (e.g., transport distance, post-harvest activities, fertilization rates, and plant mortality). Total variable costs for the seedling and liner stages combined amounted to $2.93 per liner, including $1.92 per liner for labor, $0.73 for materials, and $0.27 per liner for equipment use. The global warming potential (GWP) associated with the seedling and liner stages combined included 0.3123 kg of carbon dioxide equivalents (CO2e) for materials and 0.2228 kg CO2e for equipment use. Total farm-gate variable costs (the seedling, liner, and field production phases combined) amounted to $37.74 per marketable tree, comprised of $9.90 for labor, $21.11 for materials, and $6.73 for equipment use, respectively. However, post-harvest costs (e.g., transportation, transplanting, take-down, and disposal costs) added another $33.78 in labor costs and $27.08 in equipment costs to the farm-gate cost, yielding a total cost from seedling to end of tree life of $98.60. Of this, $43.68 was spent on labor, $21.11 spent on materials, and $33.81 spent on equipment during the life cycle of each marketable tree. As per an earlier study, the life cycle GWP of the described redbud tree, including greenhouse gas emissions during production, transport, transplanting, take-down, and disposal, would be a negative 63 kg CO2e (Ingram et al., 2013). These combined data can be used to communicate to the consuming public the true (positive) value of trees in the landscape.

The carbon footprint of a product is a measure of all greenhouse gases (GHG) emitted in a product’s life cycle and is measured in units of tons (or kg) of CO2e. It is the impact indicator of primary interest to many stakeholders because it quantifies the GWP of a product or service. Because most GHG are produced through burning fossil fuels, the carbon footprint of a product is primarily related to energy consumption. The primary GHG is carbon dioxide (CO2) and the GWP of any greenhouse gas is compared with the GWP of CO2, which is set at 1.0. CO2 evolution through such processes as burning fossil fuel has a negative impact and CO2 uptake or sequestration has a long-term positive impact on the atmosphere. A carbon footprint is expressed as the net pounds or kilograms of CO2 (or equivalence of other greenhouse gases such as CH4 and N2O) released per functional unit of the product.

Life cycle assessment (LCA) is an approach that analyzes the flows associated with the whole life cycle of a product or a service, usually referred to as “cradle-to-grave” (i.e., from raw material extraction, to manufacturing, use, recovery, and end-of-life). The first step in LCA is identifying the processes or steps for each stage in the life cycle. The inputs (materials and energy) and outputs (releases to air, water, soil, etc.) are determined for each step, evaluated for GWP, and summarized as the basis for drawing conclusions and improving future results.

The green industry supply chain includes input suppliers (manufacturers and distributors); production firms such as nursery, greenhouse, and sod growers; wholesale distribution firms including importers, brokers, re-wholesalers, and transporters; horticultural service firms providing landscape and urban forestry services such as design, installation, and maintenance; and retail operations including independent garden centers, florists, home improvement centers, and lawn/garden departments at home centers, mass merchandisers, or other chain stores. Despite being referred to as the green industry, there have been concerns expressed in the mass media about the environmental friendliness of the industry given its prominent use of petroleum-based inputs (Evans and Hensley, 2004).

Many current economic trends and driving forces point to the fact that the green industry is in a period of hypercompetitive rivalry as a result of the consumer demand exhibiting characteristics of being in the maturity stage of the industry life cycle (Hall, 2010). However, the industry is a vital component of the economy in individual states and nationally, contributing $175.3 billion in economic contributions (Hall et al., 2011). The home landscapes that are provided by the green industry also represent a substantial return on investment for homeowners, generating $1.09 to $1.35 in return for every dollar invested (Behe et al., 2005; Stigall and Elam, 2009).

Although it is widely recognized that landscape trees and plants enhance property values, these plant materials also provide measurable and lasting environmental benefits. For example, trees, shrubs, and flowers sequester carbon, reduce energy use, mitigate water runoff, and clean the air. Recently, university researchers have quantified the value of a subset of these ecosystem services (Ingram, 2012, 2013). However, no study to date has captured the economic costs of component horticultural systems while conducting a LCA of any green industry product. This study attempts to fill that void using procedures first developed by Norris (2001). Knowing the carbon footprint of production and distribution components of field-grown trees will help nursery managers understand the environmental costs associated with their respective systems and evaluate potential system modifications to reduce GHG emissions. The dynamic nature of the cost/GHG relationship needs to be understood fully to ascertain the tradeoffs that may occur.

During their useful life, trees have a significant, positive impact on atmospheric GHG. The life cycle GWP of the described redbud tree, including GHG emissions during production, transport, transplanting, take-down, and disposal, would be a negative 63 kg CO2e (Ingram et al., 2012). These data can be used to communicate to the consuming public the positive economic and environmental value of trees in the landscape.

Materials and Methods

The nursery production system modeled in this study was a field-grown, 5-cm (2-in)
The partial budgeting technique compares the sensitivity of related costs and potential benefits associated with short-run changes in cultural practices in the production systems analyzed. This is a proven technique widely cited in the literature (23 citations in the HortScience archive alone) and is used when comparing two or more similar production systems (Hunter et al., 2012; Sumtani et al., 2012; Villardon et al., 2011). Usually the comparison is between a benchmark system and one or more alternatives, as is the case in this project.

The post-harvest practices for these operations were considered when analyzing the impacts of changing management practices or reduced inputs; and 4) income that may be lost when substituting one crop for another in the production system.

This study focused entirely on the cost-related items (i.e., first and third effects). The sensitivity of the results to various production input prices, wage rates, and operational conditions was investigated by altering values of the selected variables, one at a time, from the baseline values.

As mentioned, the model production system for flowering trees consists of a seedling stage, a liner stage, and a field production stage. The costs of producing trees were delineated according to these individual stages of production. Each stage of the production system was modeled by incorporating best management practices for the field nursery stage. To ground-truth each system, interviews with nursery managers ensured that the model systems reflected cultural practices considered to be the norm for the industry. Of course, the life cycle of the tree extends well beyond the farm gate and the costs associated with getting the tree to the landscape, planting, and eventual take-down and disposal were also captured in this analysis.

For each stage, cultural practices from the fallow year to the harvest were defined and the costs of labor, materials, and equipment use estimated (Table 1). The amount of time to perform each cultural practice was then multiplied by the wage rate and then divided by the number of marketable seedlings produced in the field nursery stage. To ground-truth each system, interviews with nursery managers ensured that the model systems reflected cultural practices considered to be the norm for the industry.
Seedling production phase

Process description | GWP of materials used (kg CO₂e) | GWP of equipment used (kg CO₂e) | Labor cost/marketable seedling ($) | Material costs/marketable seedling ($) | Equipment use cost/marketable seedling ($) | Total variable cost/marketable seedling ($)
---|---|---|---|---|---|---
Fallow year | 0.000059 | 0.000049 | $0.000014 | $0.000067 | $0.000023 | $0.000104
Sow sudex—fallow year | 0.000038 | 0.000019 | $0.000011 | $0.000025 | $0.000009 | $0.000036
Chisel plow | 0.000019 | 0.000005 | $0.000005 | $0.000016 | $0.000016 | $0.000037
Disk | 0.000424 | 0.000019 | $0.000005 | $0.000011 | $0.000011 | $0.000030
Apply agricultural lime | 0.000038 | 0.000011 | $0.000011 | $0.000025 | $0.000025 | $0.000036
Mow twice | 0.000038 | 0.000011 | $0.000011 | $0.000025 | $0.000025 | $0.000036
Turning plow | 0.000038 | 0.000011 | $0.000011 | $0.000025 | $0.000025 | $0.000036
Seedling stage | 0.000168 | 0.000052 | $0.000011 | $0.000015 | $0.000015 | $0.000030
Obtain seed | 0.000057 | 0.000016 | $0.000024 | $0.000062 | $0.000062 | $0.000086
Obtain and scarify seed | 0.000012 | 0.000004 | $0.000010 | $0.000030 | $0.000030 | $0.000060
Sow seed | 0.000116 | 0.000032 | $0.000015 | $0.023529 | $0.023529 | $0.023529
Spread sawdust | 0.000122 | 0.000032 | $0.000015 | $0.023529 | $0.023529 | $0.023529
Apply herbicide | 0.000012 | 0.000004 | $0.000010 | $0.000030 | $0.000030 | $0.000060
Other herbicide | 0.000007 | 0.000002 | $0.000002 | $0.000010 | $0.000010 | $0.000020
in tank mix | 0.000159 | 0.000030 | $0.000010 | $0.000030 | $0.000030 | $0.000060
Cultivate | 0.000160 | 0.000032 | $0.000011 | $0.000030 | $0.000030 | $0.000060
Observe and irrigate | 0.000015 | 0.000003 | $0.000003 | $0.000010 | $0.000010 | $0.000020
Irrigation; T-tape | 0.000032 | 0.000006 | $0.000010 | $0.000017 | $0.000017 | $0.000034
Irrigation; lay-flat supply lines | 0.000010 | 0.000002 | $0.000002 | $0.000004 | $0.000004 | $0.000008
Irrigation labor | 0.000032 | 0.000006 | $0.000010 | $0.000017 | $0.000017 | $0.000034
Harvest seedlings | 0.000030 | 0.000006 | $0.000010 | $0.000017 | $0.000017 | $0.000034
Transport to barn | 0.000020 | 0.000010 | $0.000005 | $0.000010 | $0.000010 | $0.000020
Grade & sort | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
Transportation subtotal | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
Transport to nursery #2 | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
Office electricity | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
Gas for truck, all-terrain | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
vehicle, etc. | 0.000122 | 0.000047 | $0.000015 | $0.000047 | $0.000047 | $0.000093
Semivariable costs subtotal | 0.000194 | 0.000079 | $0.000024 | $0.000079 | $0.000079 | $0.000158
Total for seedling stage | 0.003790 | 0.004574 | $0.019604 | $0.028629 | $0.028629 | $0.050421

Seedling production phase

To determine the final number of marketable trees, a grower-determined shrink or scrap rate of 15%, 25%, and 10% was used for the seedling, liner, and field production stages, respectively. Input prices were obtained from 2012 price lists of green industry manufacturers and distributors and averaged when multiple prices were obtained. Lastly, the cost of operating each piece of machinery and equipment was derived from published enterprise budgets (Hall et al., 2002; Hinson et al., 2008; Jeffers et al., 2010), converted to current dollars using the GDP price deflator, and then multiplied by the number of hours each tractor or implement was used and then divided by the total number of seedlings to obtain the equipment-related cost per seedling. Total variable costs were derived by summing the total labor, materials, and equipment costs.

Fixed or overhead costs (depreciation, interest, repairs, taxes, insurance, and other general overhead items such as management salaries) were not a part of this study because they may vary dramatically among nursery growers as a result of differences in each nursery firm’s asset base (land, buildings, etc.). More importantly, only direct or variable costs were necessary because we were evaluating the associated costs of activities used in producing flowering redbud trees as part of the LCA. The only exceptions were the semivariable costs associated with electricity used in the office and gas used for vehicles on the nursery. These were included in the analysis because of their semivariable nature and their documented influence on GHG emissions (Ingram, 2013). It is important to note, however, that industry gross margins typically range from 48% to 52% for field-grown nurseries (American Nursery and Landscape Association, 2003); thus, the portion of costs contained here for the tree production stages would represent roughly half of the total costs one might expect to find across the industry.

**Results and Discussion**

Total variable costs incurred during the seedling stage were slightly over $0.05 per marketable seedling. This was made up of $0.020, $0.029, and $0.002 for labor, materials, and equipment operating costs, respectively. These costs are necessarily small when expressed on a per-unit basis as a result of the high planting density of redbud seedlings.

Also included in Tables 1 to 3 are columns reflecting the GWP associated with the materials and equipment used while performing each cultural practice (labor constitutes no GWP). As stated earlier, GHG (primarily CO₂, N₂O, and CH₄) are expressed in relation to the GWP potential of CO₂ in a standard 100-year assessment period (Ingram, 2013) and are presented in kilograms CO₂e, as indicated in the first two columns of each table. The GWP of materials and equipment used during the seedling stage of production was 0.0038 kg CO₂e and 0.0046 kg CO₂e, respectively.

The liner phase of the model production system involved taking the seedlings produced during the seedling phase and transplanting them in the field. Costs of $1.90, $0.70, and $0.27 were accumulated during the liner stage for labor, materials, and equipment use, respectively (Table 2). Most of the costs were incurred while performing labor and equipment intensive cultural practices such as transplanting, staking, suckering and pinching, and removing stakes.

Total variable costs for the seedling and liner stages combined amounted to $2.93 per liner, including $1.92 per liner for labor, $0.73 for materials, and $0.27 per
liners for equipment use. The GWP associated with the seedling and liner stages combined included 0.3123 kg CO$_2$e for materials and 0.2228 kg CO$_2$e for equipment use. These values represent the contributions of equipment use, input materials, and transportation of the liner to the field nursery. From this, the carbon sequestered in the tree during production would be subtracted.

The final phase, field production, represents the bulk of the costs incurred during the production of landscape-sized flowering trees (Table 3). This is mainly because it is a 4-year process that is very labor- and equipment-intensive and the comparatively low population per hectare, which increases costs on a per-unit basis. A total of $34.81 was spent performing all of the cultural practices necessary to produce a marketable 5-cm caliper redbud tree during the field production stage. The most expensive cultural practices included transplanting the liner, digging with a tree spade, and loading and unloading activities. The GWP associated with the field production stage included 4.9574 kg CO$_2$e for materials and 12.1947 kg CO$_2$e for equipment use but was offset by 10.5395 kg CO$_2$ being sequestered in the tree during production (Ingram and Hall, 2013).

Total farm-gate variable cost (the seedling, liner, and field production phases combined) amounted to $37.74 per marketable tree, comprised of $9.90 for labor, $21.11 for materials, and $6.73 for equipment use, respectively. However, post-harvest costs (e.g., transportation, transplanting, take-down, and disposal costs) added another $33.78 in labor costs and $27.08 in equipment costs to the farm-gate cost, yielding a total cost from seedling to end of tree life of $98.60. Of this, $43.68 was spent on labor, $21.11 spent on materials, and $33.81 spent on equipment use during the life cycle of each marketable tree. Again, it is important to note that only variable labor and materials costs are included even in the post-farm-gate costs; industry benchmarks show that these typically represent only $33% of the total costs arborists and other service providers would actually incur (Lawn and Landscape, 2012).

An important feature of a modeling system using LCA within an economic engineering framework is the ability to determine the sensitivity of the system to impact of possible production system component modifications. In other words, the effect of varying one particular input on associated costs can be measured (holding all other inputs constant). One area of concern in any LCA study is transportation-related impacts because those receive the bulk of attention from the media. In this model system, transporting each finished tree 240 miles (the mean distance among study cooperators) would result in GHG emissions of 3.891 kg CO$_2$e and reducing that to 100 miles would reduce the GWP by 58% (1621 kg CO$_2$e) and saving $2.63 per marketable tree.

The analysis of the production system components revealed that 29.7% of the total costs arborists incurred during harvest and loading trucks. The processes of loading trees in the field, hauling them to a shipping area, setting them off the
wagon, and later loading them on a truck contributed 5.1026 kg CO\textsubscript{2}e to the GWP of the product at a cost of $5.03. If the nursery could increase the efficiency of these operations (e.g., by reducing wasted movements or incorporating other lean management principles) and reduce the time required by 25%, the GWP would be reduced by 1.701 to 4.402 kg CO\textsubscript{2}e and the cost would be reduced by $1.68 to $3.35 for harvest operations.

Another area of concern in the environmental policy arena lies in the area of fertilizer application. The environmental impacts of fertilizer use are significant, with the potential for soil and water contamination and increased greenhouse gas emissions. The nursery could reduce its environmental footprint by adopting more sustainable practices, such as using organic fertilizers or improving irrigation techniques to minimize water runoff. This would not only benefit the environment but also potentially save money in the long run.

### Table 3. Greenhouse warming potential (GWP; kg CO\textsubscript{2}e) and variable labor, materials, and equipment costs associated with cultural practices in a model nursery production system for a field-grown, 5-cm caliper *Cercis canadensis* L. ‘Forest Pansy’ tree.

<table>
<thead>
<tr>
<th>Process description</th>
<th>GWP of materials used (kg CO\textsubscript{2}e)</th>
<th>GWP of equipment used (kg CO\textsubscript{2}e)</th>
<th>Labor cost/marketable tree ($)</th>
<th>Material costs/marketable tree ($)</th>
<th>Equipment use cost/marketable tree ($)</th>
<th>Total variable cost/marketable tree ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Field production phase</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Fallow year</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plow 1 time/2 directions</td>
<td>0.131462</td>
<td>$0.037535</td>
<td>$0.000000</td>
<td>$0.088056</td>
<td>$0.125590</td>
<td></td>
</tr>
<tr>
<td>Disk 2 times</td>
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<td>$0.018767</td>
<td>$0.000000</td>
<td>$0.032625</td>
<td>$0.051392</td>
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</tr>
<tr>
<td>Lime application</td>
<td>0.738646</td>
<td>$0.009384</td>
<td>$0.027778</td>
<td>$0.027438</td>
<td>$0.064599</td>
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<td>Sudex—fallow year</td>
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<td>$0.024398</td>
<td>$0.116667</td>
<td>$0.040896</td>
<td>$0.181960</td>
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</tr>
<tr>
<td>Turn under cover crop</td>
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<td>$0.018767</td>
<td>$0.000000</td>
<td>$0.030306</td>
<td>$0.049073</td>
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<td>Disk</td>
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<td>$0.018767</td>
<td>$0.000000</td>
<td>$0.032625</td>
<td>$0.051392</td>
<td></td>
</tr>
<tr>
<td>Rotovilling</td>
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<td>$0.029948</td>
<td>$0.044023</td>
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<td>Transport liners to field</td>
<td>0.002636</td>
<td>$0.004692</td>
<td>$0.005226</td>
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<tr>
<td>Transplant liners</td>
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<td>$0.075069</td>
<td>$13.333333</td>
<td>$0.041542</td>
<td>$13.449944</td>
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<tr>
<td>Sow fescue in middles</td>
<td>0.102486</td>
<td>$0.085450</td>
<td>$0.024398</td>
<td>$0.116667</td>
<td>$0.040896</td>
<td>$0.181960</td>
</tr>
<tr>
<td>Turn under cover crop</td>
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<td>$0.018767</td>
<td>$0.000000</td>
<td>$0.030306</td>
<td>$0.049073</td>
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</tr>
<tr>
<td><strong>Field year 2</strong></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>Apply fertilizer</td>
<td>0.451228</td>
<td>$0.009384</td>
<td>$0.032625</td>
<td>$0.051392</td>
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<td></td>
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<tr>
<td>Apply herbicides</td>
<td>0.042715</td>
<td>$0.037534</td>
<td>$0.085750</td>
<td>$0.086334</td>
<td>$0.209618</td>
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<td>Apply insecticides</td>
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<td>$0.039063</td>
<td>$0.010451</td>
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<td>$0.018767</td>
<td>$0.028694</td>
<td>$0.047462</td>
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<td></td>
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<td>Pruning and training</td>
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<td>$0.180167</td>
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</tr>
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<td>$0.009384</td>
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<td>$0.051392</td>
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<tr>
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<td>$0.085750</td>
<td>$0.086334</td>
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<td>$0.039063</td>
<td>$0.023789</td>
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<td>Cultivate</td>
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<td>$0.028694</td>
<td>$0.047462</td>
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<tr>
<td>Pruning and training</td>
<td>$0.180167</td>
<td>$0.180167</td>
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<tr>
<td>Mowing</td>
<td>0.065839</td>
<td>$0.037535</td>
<td>$0.063778</td>
<td>$0.101313</td>
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<td></td>
</tr>
<tr>
<td><strong>November of third year and February/March Year 4</strong></td>
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<td>Digging with tree spade</td>
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<td>$3.062833</td>
<td>$4.570000</td>
<td>$1.531432</td>
<td>$9.164265</td>
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<tr>
<td>Loading in field</td>
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<td>$1.216125</td>
<td>$1.048000</td>
<td>$2.264125</td>
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<td>$1.424500</td>
<td>$2.1010125</td>
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<tr>
<td>Unloading and loading</td>
<td>2.218666</td>
<td>$1.216125</td>
<td>$1.048000</td>
<td>$2.1010125</td>
<td></td>
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</tr>
<tr>
<td>Removal of culls</td>
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<td>$0.325301</td>
<td>$0.184722</td>
<td>$0.510023</td>
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<td></td>
</tr>
<tr>
<td>Post-harvest wagon use</td>
<td>0.058342</td>
<td>$0.094444</td>
<td>$0.094444</td>
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<td></td>
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<tr>
<td><strong>Production activity subtotal</strong></td>
<td>3.653336</td>
<td>$7.974877</td>
<td>$20.073726</td>
<td>$6.454201</td>
<td>$34.502804</td>
<td></td>
</tr>
<tr>
<td>Office electricity</td>
<td>0.670000</td>
<td>$0.106000</td>
<td>$0.106000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pickup truck gas</td>
<td>0.634111</td>
<td>$0.201667</td>
<td>$0.201667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Subtotal for semi-variable costs</strong></td>
<td>1.304111</td>
<td>$0.307667</td>
<td>$0.307667</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total field nursery stage</strong></td>
<td>4.957447</td>
<td>$12.194784</td>
<td>$20.381392</td>
<td>$6.454201</td>
<td>$34.810471</td>
<td></td>
</tr>
<tr>
<td><strong>Total farm gate variable cost</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport to landscaper</td>
<td>3.891231</td>
<td>$5.200000</td>
<td>$5.200000</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transport by landscaper</td>
<td>2.283741</td>
<td>$0.675625</td>
<td>$1.197500</td>
<td>$2.1010125</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transplant tree at site</td>
<td>0.919433</td>
<td>$10.810000</td>
<td>$0.948912</td>
<td>$11.758912</td>
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<td></td>
</tr>
<tr>
<td><strong>End-of-life take-down and disposal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck (heavy); 6 mpg</td>
<td>45.665035</td>
<td>$13.512500</td>
<td>$4.570000</td>
<td>$1.531432</td>
<td>$9.164265</td>
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</tr>
<tr>
<td>Cut down and cut up tree</td>
<td>2.218666</td>
<td>$0.675625</td>
<td>$1.197500</td>
<td>$2.1010125</td>
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<td></td>
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<tr>
<td>Chipper (140 hp)</td>
<td>38.336634</td>
<td>$6.756250</td>
<td>$12.500000</td>
<td>$19.256250</td>
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<td></td>
</tr>
<tr>
<td><strong>Total post farm gate variable cost (seedling to finished tree)</strong></td>
<td>$33.781250</td>
<td>$27.080000</td>
<td>$60.861250</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total variable cost from seedling to end of tree life</strong></td>
<td>$43.679172</td>
<td>$21.113958</td>
<td>$33.805494</td>
<td>$98.598624</td>
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</tr>
</tbody>
</table>
use during the field production phase. If one-third more (less) fertilizer was used than the recommended rate, GWP would increase (decrease) by 0.396 kg CO₂e and $0.28 would be added to (deducted from) the variable cost of the tree.

If plant mortality were impacted by the cull rate during the final field production phase and losses were 15% instead of the assumed 10%, GWP assigned to each marketable tree at the farm gate would increase by 0.6193 kg CO₂e and increase the variable cost of each tree by $1.42. One might expect the impact of an additional 5% culls to have a greater impact on GWP and cost; however, culls would not be harvested and 63% of GHG emissions occur at harvest. This scenario includes the GWP and costs associated with removing the additional culls. If the time required for the field production phase was 4 years instead of the assumed 3 years, the GWP per tree would increase by only 1.18 kg CO₂e and the variable costs by $0.75.

Labor is obviously a major component of the cost structure for the modeled production system. The average 2012 Adverse Wage Rate of $10.81 was used in the study. If the 90th percentile wage rate of $12.46 for nursery and greenhouse farmworkers as reported by the Bureau of Labor Statistics were used instead of the Adverse Wage Rate, variable labor costs would have increased by 15%. Total costs incurred during the entire life cycle would have risen from $98.60/tree to $105.27/tree. The sensitivity to the overall cost structure can also be applied to other types of increased labor expenses that are expected in the future (e.g., Affordable Care Act).

**Conclusions**

As the green industry continues to mature, differentiation is an increasingly important business strategy for green industry businesses. One such way to accomplish this is by exhibiting environmentally friendly behaviors and/or selling products that offer environmental benefits. Consumers’ awareness and concern about environmental issues are exhibited by their interest in purchasing products that are designed to reduce long-term adverse environmental impacts. With regard to the green industry, the relationship between environmentally friendly business practices and consumer preferences suggests that nurseries growing trees may realize financial benefits for their efforts toward designing environmentally sound products. In the current example, planting more trees that more than offset the amount of GHG that are generated during their production by the amount of GHG they sequester during their lifespan could be emphasized during firm-level marketing efforts.

The findings from this research validate those of previous studies that found that input costs of production processes (machinery, water, fertilizers, pesticides, and energy) are a significant portion of the nursery variable operation costs. Thus, a more efficient use of these environmentally sensitive inputs cannot only reduce production costs for the nursery, but reduce their environmental risks or impacts as well. In this study, LCA has been shown to be an effective tool for nursery growers in understanding the inputs, outputs, and impacts of systems producing field-grown trees. It has also provided a linear time-oriented way of allocating costs to those systems. Information gained from this cost analysis and LCA of field-grown ornamental tree production systems will help managers better understand the economic dimensions of their production systems and associated cultural practices and help them better articulate an improved value proposition for their products in the green industry marketplace.

**Literature Cited**


