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

Charles R. Hall[1,2,3]
Department of Horticultural Sciences, Texas A&M University, 2133 TAMU, College Station, TX 77843-2133

Dewayne Ingram[1]
Department of Horticulture, University of Kentucky, N-308F Agri. Science Center, Lexington, KY 40546-0091

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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 (CO_2e) for materials and 0.2228 kg CO_2e 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 use 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 CO_2e (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 CO_2e. 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 (CO_2) and the GWP of any greenhouse gas is compared with the GWP of CO_2, which is set at 1.0. CO_2 evolution through such processes as burning fossil fuel has a negative impact and CO_2 uptake or sequestration has a long-term positive impact on the atmosphere. A carbon footprint is expressed as the net pounds or kilograms of CO_2 (or equivalence of other greenhouse gases such as CH_4 and N_2O) 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; Stigarll 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 CO_2e (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)

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[1] Professor.

[2] Ellison Chair in International Floriculture.

[3] To whom reprint requests should be addressed; e-mail chall@ag.tamu.edu.

caliper *Cercis canadensis* 'Forest Pansy' in the Lower Midwest. This flowering tree was selected as representative of the flowering tree category because of its prominence in the geographic area being studied. It is important to recognize that we report results in per-tree equivalent units (EQUs). EQUs are used by some nursery operations to track the costs associated with producing different products, namely different-sized trees. By reporting study outcomes in per EQU, the cost and GHG inventory can be used to estimate the performance of additional tree product sizes not considered in this study. There is significant variation in production system protocols used by nursery growers in the region but a model system incorporating best management practices was described after interviews with three nursery managers. The model production system in this study includes seedling production in a specialized nursery using in-row, field production encompassing one growing season. Seeds would be purchased from a nearby collector. The field would be planted with a cover crop during a fallow year every fourth year and then prepared for sowing of redbud seed. The resulting seedlings from the first nursery would be transported 48 km (30 mi) to a second nursery that would grow the plants in rows on 20-cm (8-in) centers in the spring. 'Forest Pansy' buds would be chip-budded onto the seedlings in August. Plants would be staked and trained throughout that growing season before a December to February harvest after the second growing season. The resulting 1.5 to 1.8 m (5 to 6 ft), lightly branched, bare root liners would be shipped 402 km (250 mi) to a third nursery where they would be transplanted in the field in March or April after a fallow year with a cover crop. After three growing seasons, the trees would be harvested as a 5-cm (2-in) caliper, spade-dug finished product. The tree would be shipped an average of 386 km (240 mi), 120 trees per tractor trailer transporter, and transplanted into a favorable landscape site.

This LCA portion of the study followed published standards of the International Organization for Standardization (Geneva, Switzerland), and PAS 2050 guidelines by BSI British Standards (B.S.I., 2011). Equipment use and input products were inventoried and their individual GHG emissions were determined, converted to kg CO_2e per functional unit, and summed. Emissions from the manufacturing of capital goods such as buildings and machinery were not included in this study as per PAS 2050, Section 6.4.4 (3). Impact of land use change was not included in this study because it was assumed that the farms have been in agricultural production for at least 50 years and in nursery production for at least 20 years. Other details regarding the LCA procedures and input materials and equipment use are detailed in Ingram and Hall (2013).

As mentioned earlier, the main objective here is to provide the detailed results of the cost analysis portion of the study. Thus, only the summary results of the LCA are provided in this article; more details are provided in Ingram and Hall (2013). The entire production system for redbud production was modeled using an economic engineering approach. It is important to note that only variable costs of each cultural practice (activity) were included in the analysis. This is common practice when using a partial budgeting economic framework. Facilities may vary significantly among successful operations in the industry; therefore, corresponding fixed costs also vary accordingly. Because of this, fixed costs associated with land, buildings, and other structures were not included in the analysis. This approach follows Hinson et al. (2008) in which the authors make a case for departing from traditional economic engineering methods as a result of the extreme differential that exists among nursery firms in terms of the leverage and other fixed costs associated their asset base.

Following previously referenced enterprise budgeting procedures for ornamental crops (Hall et al., 2002; Hinson et al., 2008; Jeffers et al., 2010), the amount of labor required to perform each cultural practice or activity was tracked as was the amount of time machinery and equipment was operated and the amount of materials that were used (e.g., fertilizers, pesticides, etc.). Based on the advice from cooperating growers, the amount of labor needed to perform each activity in the nursery was multiplied by a factor of 1.25 to account for non-productive time such as setup, cleanup, etc. The Adverse Effect Wage Rate (AEWR) of \$10.81 was used, which is the average minimum wage that the U.S. Department of Labor has determined for the states included in the Lower Midwest region (Kentucky, Ohio, Indiana, Illinois, Montana, Kansas, and Oklahoma) where these trees are typically produced in field nurseries (D.O.L., 2012a, 2012b). The AEWR represents the wage level that must be offered and paid to U.S. and alien workers by agricultural employers of nonimmigrant H-2A agricultural workers. Costs of materials were valued at 2012 prices obtained from green industry wholesale distributors and manufacturers. Equipment costs per hour were representative of those reported in enterprise budgets for horticultural crops produced in the Lower Midwest region (Iowa State University Extension, 2005; University of Kentucky Center for Crop Diversification, 2012; University of Illinois, 2010). The diesel fuel price of \$3.63 per gallon (\$13.74/L) represented the U.S. average as reported by the Energy Information Administration (E.I.A., 2012).

Partial budget 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. 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; Samtani et al., 2012; Villordon et al., 2011). Usually the comparison is between a benchmark system and one or more alternatives, as is the case in this project.

The partial budgeting technique compares the negative effects (costs added) of applying a new treatment relative to a base or standard treatment with the positive effects (cost savings) associated with the new treatment relative to the base or standard treatment. Therefore, in this project, it requires the consideration of the returns associated with treatments and changes in the structure of the production costs. Aspects of costs and returns that do not change with the treatment relative to the base are not considered in this portion of the analysis. Thus, the technique of partial budgeting examines only the effect of the proposed change in practice, assuming all other aspects of the green industry value chain remain unchanged. This is done by considering the physical changes associated with the alternatives being proposed and then determining the effects of these changes on the financial position of the business using, in this case, total variable costs of production as a proxy.

The typical partial budgeting approach measures overall project impact by measuring four separate effects including: 1) added costs of production incurred by the use of alternative materials, cultural practices; 2) added income resulting from increased levels of production and/or price premiums associated with higher quality crops; 3) costs savings realized through more efficient 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 industry. 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 to obtain the labor cost per marketable seedling. Similarly, the cost of each of the materials used in performing each cultural practice was recorded, then multiplied by each input price to obtain the total materials costs, and then divided by the number of marketable seedlings to obtain the cost per

Table 1. Greenhouse warming potential (GWP; kg CO_2e) and variable labor, materials, and equipment costs associated with cultural practices in a model production system for a field-grown seedling of *Cercis canadensis* L. 'Forest Pansy'.

Process description	GWP of materials used (kg CO_2e)	GWP of equipment used (kg CO_2e)	Labor cost/marketable seedling ($)	Material costs/ marketable seedling ($)	Equipment use cost/ marketable seedling ($)	Total variable cost/ marketable seedling ($)
Seedling production phase						
Fallow year						
Sow sudex—fallow year	0.000059	0.000049	$0.000014	$0.000067	$0.000023	$0.000104
Chisel plow		0.000038	$0.000011		$0.000025	$0.000036
Disk		0.000019	$0.000005		$0.000009	$0.000015
Apply agricultural lime	0.000424	0.000019	$0.000005	$0.000016	$0.000016	$0.000037
Mow twice		0.000038	$0.000011		$0.000019	$0.000030
Turning plow		0.000038	$0.000011		$0.000025	$0.000036
Seedling stage						
Obtain seed				$0.001681		$0.001681
Obtain and scarify seed			$0.000052	$0.000451		$0.000503
Disk		0.000057	$0.000016		$0.000028	$0.000044
Rototill		0.000085	$0.000024		$0.000052	$0.000076
Layoff rows		0.000010	$0.000010		$0.000010	$0.000020
Sow seed			$0.000155	$0.023529		$0.023685
Spread sawdust (cover seed)	0.000116	0.000122	$0.000032	$0.000048	$0.000060	$0.000140
Apply fertilizer	0.000808	0.000124	$0.000221	$0.000796	$0.000513	$0.001530
Apply herbicide	0.000269	0.000014	$0.000016	$0.001194	$0.000044	$0.001154
Other herbicide in tank mix	0.000067			$0.000314		$0.000314
Cultivate		0.000159	$0.000151		$0.000159	$0.000310
Observe and irrigate		0.000115			$0.000180	$0.000180
Irrigation; T-tape	0.000160		$0.000207	$0.000588		$0.000795
Irrigation; lay-flat supply lines	0.000008			$0.000017		$0.000017
Irrigation labor			$0.000310			$0.000310
Harvest seedlings		0.000030	$0.000032		$0.000049	$0.000081
Transport to barn		0.000206	$0.004769		$0.000213	$0.004982
Grade & sort			$0.013513			$0.013513
Production activity subtotal	0.001844	0.001121	$0.019565	$0.028288	$0.001426	$0.049279
Transport to nursery #2		0.003452	$0.000039		$0.000763	$0.000801
Transportation subtotal		0.003452	$0.000039		$0.000763	$0.000801
Office electricity	0.001282			$0.000124		$0.000124
Gas for truck, all-terrain vehicle, etc.	0.000664			$0.000217		$0.000217
Semivariable costs subtotal	0.001946			$0.000341		$0.000341
Total for seedling stage	0.003790	0.004574	$0.019604	$0.028629	$0.002188	$0.050421

seedling. 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 CO_2, N_2O, and CH_4) are expressed in relation to the GWP potential of CO_2 in a standard 100-year assessment period (Ingram, 2013) and are presented in kilograms CO_2e, 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 CO_2e and 0.0046 kg CO_2e, 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

Table 2. Greenhouse warming potential (GWP; kg CO_2e) and variable labor, materials, and equipment costs associated with cultural practices in a model production system for a field-grown liner of *Cercis canadensis* L. 'Forest Pansy'.

Process description	GWP of materials used (kg CO_2e)	GWP of equipment used (kg CO_2e)	Labor cost/ marketable liner ($)	Material costs/ marketable liner ($)	Equipment use cost/marketable liner ($)	Total variable cost/marketable liner ($)
Liner production phase (2 years)						
Fallow year						
Sow sudex—fallow year	0.004730	0.003792	$0.001083	$0.005385	$0.001815	$0.008282
Chisel plow		0.006067	$0.001732		$0.004064	$0.005796
Disk		0.003034	$0.000866		$0.001506	$0.002372
Mow twice		0.003034	$0.000866		$0.001452	$0.002318
Liner stage						
Plow		0.006067	$0.001732		$0.004064	$0.005796
Disk		0.006067	$0.001732		$0.003012	$0.004744
Rototill		0.006067	$0.001732		$0.003686	$0.005418
Transplant		0.003115	$0.005544	$0.375000	$0.008952	$0.389495
Sow crimson clover	0.058636	0.000730	$0.001299	$0.053333	$0.000886	$0.055518
Mow middles		0.001218	$0.001155		$0.000940	$0.002095
Hoe weeds			$0.011087			$0.011087
Bud wood			$0.028827			$0.028827
Chip budding				$0.046107		$0.046107
Remove seedling shoot		0.000808	$0.014090		$0.000835	$0.014925
Take tape off and cut suckers			$0.016631			$0.016631
Stake liners	0.032777	0.003893	$0.494858	$0.087880	$0.003938	$0.586676
Suckering and taping			$0.989716			$0.989716
Cultivate		0.002725	$0.004851		$0.003608	$0.008458
Irrigate through T-tape	0.005051	0.003084	$0.011087	$0.017846	$0.004825	$0.033758
Irrigation supply line	0.000454			$0.000932		$0.000932
Maintain irrigation system			$0.016631			$0.016631
Apply insecticides	0.001016	0.006442	$0.003464	$0.033199	$0.012198	$0.048861
Apply fertilizer	0.043335	0.002920	$0.005197	$0.042692	$0.010027	$0.057916
Apply herbicides	0.006978	0.004153	$0.007391	$0.018390	$0.017001	$0.042783
Mow roadways		0.000122	$0.000069		$0.000084	$0.000153
Removing stakes		0.005332	$0.240222		$0.005513	$0.245735
Harvest—shaker/digger		0.026211	$0.027718		$0.010440	$0.038158
Transport to barn and grade/store		0.003433	$0.008315		$0.007762	$0.016077
Load truck—to customer			$0.005544			$0.005544
Production activity subtotal	0.152978	0.098316	$1.903441	$0.680763	$0.106605	$2.690809
Office electricity	0.118935			$0.011538		$0.011538
Gas for pickup truck, all-terrain vehicle, etc.	0.036583			$0.011635		$0.011635
Subtotal for semivariable costs	0.155518			$0.023173		$0.023173
Transport liner		0.119876			$0.162500	$0.162500
Total for liner stage	0.308496	0.218193	$1.903441	$0.703936	$0.269105	$2.876482
Combined total for seedling and liner stages	0.312286	0.222766	$1.923044	$0.732566	$0.271293	$2.926903

liner for equipment use. The GWP associated with the seedling and liner stages combined included 0.3123 kg CO_2e for materials and 0.2228 kg CO_2e 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 liner 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_2e for materials and 12.1947 kg CO_2e for equipment use but was offset by 10.5395 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_2e and reducing that to 100 miles would reduce the GWP by 58% (1621 kg CO_2e) and the variable cost by $3.03 per marketable tree.

The analysis of the production system components revealed that 29.7% of the GHG emission and 13.3% of the costs occurred during harvest and loading trucks. The processes of loading trees in the field, hauling them to a shipping area, setting them off the

Table 3. Greenhouse warming potential (GWP; kg CO_2e) 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.

Process description	GWP of materials used (kg CO_2e)	GWP of equipment used (kg CO_2e)	Labor cost/marketable tree ($)	Material costs/ marketable tree ($)	Equipment use cost/marketable tree ($)	Total variable cost/marketable tree ($)
Field production phase						
Fallow year						
Plow 1 time/2 directions		0.131462	$0.037535	$0.000000	$0.088056	$0.125590
Disk 2 times		0.065731	$0.018767	$0.000000	$0.032625	$0.051392
Lime application	0.738646	0.032866	$0.009384	$0.027778	$0.027438	$0.064599
Sudex—fallow year	0.102486	0.085450	$0.024398	$0.116667	$0.040896	$0.181960
Turn under cover crop		0.065731	$0.018767	$0.000000	$0.030306	$0.049073
Field year 1						
Disk		0.065731	$0.018767		$0.032625	$0.051392
Rototilling		0.049298	$0.014076		$0.029948	$0.044023
Transport liners to field		0.002636	$0.004692		$0.005226	$0.009918
Transplant liners	0.585209	0.065731	$0.075069	$13.333333	$0.041542	$13.449944
Sow fescue in middles	0.028824	0.016460	$0.009384	$0.039063	$0.010111	$0.058557
Bamboo stake	0.044440	0.005272	$0.300278	$0.800000	$0.010451	$1.110729
Irrigate		0.681491	$0.045042	$0.000000	$0.025269	$0.070311
Apply fertilizer	0.270737	0.005272	$0.009384	$0.180000	$0.021819	$0.211203
Cultivate		0.032919	$0.018767		$0.028694	$0.047462
Apply herbicides	0.029599	0.021090	$0.037534	$0.085750	$0.086334	$0.209618
Apply insecticides	0.003161	0.016460	$0.011260	$0.079297	$0.014347	$0.104905
Cultivate		0.032919	$0.018767		$0.028694	$0.047462
Pruning and training			$0.180167			$0.180167
Mowing		0.065839	$0.037535		$0.063778	$0.101313
Field year 2						
Apply fertilizer	0.451228	0.005272	$0.009384	$0.300000	$0.021819	$0.331203
Apply herbicides	0.042715	0.021090	$0.037534	$0.085750	$0.086334	$0.209618
Apply insecticides	0.000097	0.016460	$0.011260	$0.046549	$0.014347	$0.072157
Cultivate		0.032919	$0.018767		$0.028694	$0.047462
Pruning and training			$0.180167			$0.180167
Mowing		0.065839	$0.037535		$0.063778	$0.101313
Field year 3						
Apply fertilizer	0.451228	0.005272	$0.009384	$0.300000	$0.021819	$0.331203
Apply herbicides	0.029599	0.021090	$0.037534	$0.085750	$0.086334	$0.209619
Apply insecticides	0.000948	0.016460	$0.011260	$0.023789	$0.014347	$0.049397
Cultivate		0.032919	$0.018767		$0.028694	$0.047462
Pruning and training			$0.180167	$0.000000	$0.000000	$0.180167
Mowing		0.065839	$0.037535	$0.000000	$0.063778	$0.101313
November of third year and February/March Year 4						
Digging with tree spade	0.848189	3.196410	$3.062833	$4.570000	$1.531432	$9.164265
Loading in field		2.218666	$1.216125		$1.048000	$2.264125
Hauling from the field		2.366318	$0.675625		$1.424500	$2.100125
Unloading and loading		2.218666	$1.216125		$1.123000	$2.339125
Removal of culls		0.410864	$0.325301		$0.184722	$0.510023
Post-harvest wagon use		0.058342			$0.094444	$0.094444
Production activity subtotal	3.653336	12.194784	$7.974877	$20.073726	$6.454201	$34.502804
Office electricity	0.670000			$0.106000		$0.106000
Pickup truck gas	0.634111			$0.201667		$0.201667
Subtotal for semi-variable costs	1.304111			$0.307667		$0.307667
Total field nursery stage	4.957447	12.194784	$7.974877	$20.381392	$6.454201	$34.810471
Total farm gate variable cost			$9.897922	$21.113958	$6.725494	$37.737374
Transport to landscaper		3.891231			$5.200000	$5.200000
Transport by landscaper		2.283741	$0.675625		$1.197500	$1.873125
Transplant tree at site		0.919433	$10.810000		$0.948912	$11.758912
End-of-life take-down and disposal						
Truck (heavy); 6 mpg		45.665035	$13.512500		$9.580000	$23.092500
Cut down and cut up tree		4.442400	$13.512500		$5.000000	$18.512500
Chipper (140 hp)		38.336634	$6.756250		$12.500000	$19.256250
Total post farm gate variable cost (seedling to finished tree)			$33.781250		$27.080000	$60.861250
Total variable cost from seedling to end of tree life			$43.679172	$21.113958	$33.805494	$98.598624

wagon, and later loading them on a truck contributed 5.1026 kg CO_2e 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_2e 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 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 CO_2e 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 CO_2e 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 CO_2e 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.

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