HORTSCIENCE 51(4):383–387. 2016.

Comparison of Carbon Footprint and Variable Costs of Selected Nursery Production Systems for a 5-cm-caliper Red Maple

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Additional index words. production costs, life cycle assessment, pot-in-pot, carbon footprint, production systems

***Abstract*. The objective of this study was to examine the differences in global warming potential (GWP) and variable cost structure of a 5-cm-caliper red maple tree grown using two alternative production methods including a traditional field [balled and burlapped (BNB)] production system and a containerized, pot-in-pot (PIP) production system. Feedback from nursery growers was obtained to model each production system including the labor required for each cultural practice, materials used, and the hourly usage of tractors and other equipment. Findings from the study indicate that the total system GWP and variable cost for the PIP tree system is −671.42 kg of carbon dioxide equivalent (CO_2e) and $250.76, respectively, meaning that the tree sequesters much more carbon during its life than is emitted during its entire life cycle. The same holds true for the BNB tree; however, in this system, the GWP of the tree −666.15 kg CO_2e during its life cycle at a total variable cost of $236.13. Thus, the BNB tree costs slightly less to produce than its PIP counterpart but the life cycle GWP is slightly less positive as well.**

The costs of producing ornamental plant species vary among alternative nursery production systems because of differences in planting procedures, growing practices (fertilizing, irrigating, pruning, etc.), and harvesting activities. Common systems used in the green industry currently include field-grown and container methods, as well as PIP systems that are a hybrid of the previous two methods. Each of these systems offer distinct advantages relative to the other systems, but there are inherent trade-offs and concessions that nursery operators make when selecting their preferred method of production.

PIP nursery production is a modified container production system used extensively in the south and increasingly in the midwest. Plastic nursery pots are set in the ground and liner pots of the same size containing the plants are inserted, making a double pot system that prevents rooting out into the soil. The pots are recessed in the ground, preventing blow over and protecting the roots from extreme temperatures, negating the need for extra winter protection. The liner pots get pulled and sold with the plant; the outside socket pots are then replanted with a new crop. The end product, a plant grown in a pine bark substrate in a large pot, is easier to handle and plant than a BNB plant.

Compared with field-grown trees, PIP requires more labor and greater investment costs at planting, but provides labor, equipment, or both savings at harvest, saves valuable topsoil, and provides a supply of fresh trees for market all season. In some parts of the country, growers have even stated that production time has also been reduced with the use of PIP.

Each of these nursery production systems also vary in terms of their environmental impacts, which are becoming increasingly important to consumers in the green industry marketplace (Hall et al., 2010; Yue et al., 2010, 2011). Although it is widely recognized that green industry products increase the function and aesthetics of the built environment and improve the quality of life of individuals in those environments, they also provide valuable ecosystem services such as sequestering carbon and elevating O_2 in the environment. However, the choice of inputs used during the production of those plants in the nursery and those used while performing related maintenance services while in the landscape will determine the degree of sustainability of the green industry (Marble et al., 2011; Prior et al., 2011).

Ingram and Hall have been exploring the carbon footprint and variable cost structure of selected nursery species (Hall and Ingram, 2014, 2015; Ingram, 2012, 2013; Ingram and Hall, 2014a, 2014b) but to date have not compared the results of alternative production systems on the same plant species of the same salable size. Given that the production protocols are now available for BNB and PIP production of similarly sized *Acer rubrum* 'October Glory' shade trees, the objective of this study was to compare the two systems to ascertain the cost and GWP differences between them.

Specifically, this analysis examines the differences in shrink (sometimes referred to as dumpage or scrap); the impacts of differing lengths of production cycles; the effects of differences in cultural practices (e.g., pruning, fertilization, etc.); PIP container costs vs. supplies for prepping BNB trees (e.g., BNB materials); differences in planting costs (e.g., smaller liner used in field production and grown for more years while the PIP model system requires a large liner but grown in less time); and transportation cost differences (e.g., weight and number of plants on a truck, as well as loading and unloading time and equipment use comparisons).

Methodology

Ingram (2012) earlier reported on the GWP of field-grown *A. rubrum* 'October Glory', but did not include the variable costs of production in that study. Ingram and Hall recently completed a study of PIP production of *A. rubrum* 'October Glory' and calculated variable costs and GWP of a model system (Ingram and Hall, 2015).

Field system overview

The field production nursery system protocol is summarized in detail in Ingram (2012). The representative model system for this study was determined through interviews with five nursery managers in Kentucky and Tennessee with experience in producing field-grown *A. rubrum* "October Glory" and consistent with general recommendations (Ingram, 2012). The time required for defined machinery to perform specific operations as well as the quantity of materials used in fertilization, pest management, staking, and harvesting operations were estimated from the nursery manager records and manufacturer recommendations. Each of the nursery managers interviewed indicated that these farms had been in agricultural production for more than 50 years, at least the past 20 years in nursery crop production. Tobacco and forage crops were predominant before shifting to nursery crop production and forage grasses cover 63% of the field surface during nursery production and 100%

Received for publication 18 Aug. 2015. Accepted for publication 21 Sept. 2015.

This study was funded in part from a grant from The Horticulture Research Institute, 1200 G Street NW, Suite 800, Washington, DC, 20005.

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in the fallow year. Therefore, the impact of land use change was not included in this analysis as per Publicly Available Specification (PAS) 2050 (BSI, 2011).

The model system was based on the production of a branched, bare-root, 2-m liner from a cutting in one nursery (liner nursery) and transporting to another nursery (field nursery) for finishing. Liner production would involve rooting cuttings in a ground bed in May and transplanting to the field the following May for one growing season. Liners would then be dug bare root in the fall, overwintered in a barn, and trucked to the field nursery in April. The field block at the second nursery (field nursery) would have previously remained fallow with a sudex cover crop for one growing season that was plowed under in the fall. A 5-cm-caliper tree would be harvested from the field nursery in the fall of the 4th year. Therefore, the entire production phase would include 2 years in the liner nursery plus almost 4 years in the field production nursery. The harvested tree would be transported to a landscaper who would transplant it into a suburban site with favorable growing conditions. After a 60-year use phase, the tree would be taken down, chipped, and used as mulch.

PIP system overview

As reported by Ingram and Hall (2015), the functional unit for the PIP system in the lower midwest was also a 5-cm-caliper red maple in a no. 25 container. This model system was also based on interviews with four nursery managers and guided by published protocols (Halcomb and Fare, 2009; Hall et al., 2002; McNiel, 2000). The boundaries for this model assumed cuttings would be taken from current nursery stock in early summer and stuck in ground beds amended with sand. Intermittent mist would be provided until cuttings rooted. After 2 years in the bed, rooted cuttings would be transplanted in rows in the field and grown for 2 years at which time 1.8 m (6 ft), branched, bare-root liners would be harvested and transported to the PIP nursery for finishing in no. 25 containers in two growing seasons. Finished trees would be pulled from the socket pots and loaded on a tractor-trailer truck for transport to the customer and transplanted into the landscape. A 60-year functional life would be followed by tree removal and disposal to compete the life cycle.

Life cycle assessment (LCA) standards were followed, including the International Organization for Standardization, Geneva, Switzerland (ISO, 2006), and PAS 2050 guidelines by BSI (2011). Input products, equipment use, and labor were inventoried for the activities in each production phase. Greenhouse gas (GHG) emissions were determined, converted to kilograms CO_2e per functional unit, and summed. Costs of inputs, equipment use, and labor were determined for both model systems (IPCC, 2006). It is important to note that 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. 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, therefore, no impact from land use change was included.

Cost calculations. An economic engineering approach was used to estimate variable costs. Fixed costs associated with buildings, land, and general overhead are highly variable between nurseries in the industry and were not included in this analysis, but typically range from 48% to 52% of total costs. The amount of labor for each operation in both models was also determined from nursery manager interviews, with follow-up Delphi method (Hsu and Sandford, 2007) discussions. Labor requirements for operating equipment were calculated as 1.25 times the equipment operation hours to account for preparation and cleanup time. Labor contributes significantly to costs but does not contribute directly to the GWP of the product.

The Adverse Effect Wage Rate (AEWR) as determined by the U.S. Department of Labor (2015) for the states included in the lower midwest region was used to set the wage rate of \$11.67. 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 input materials were 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. The gasoline price of \$0.858/L (\$3.25/gal) represented the U.S. average as reported by the U.S. Energy Information Administration (2014).

Inventory analysis and data collection

Estimated tractor horsepower (hp) requirements for each function were determined through nursery manager interviews. The portion of maximum tractor throttle and load for each operation is summarized in the aforementioned articles. The GWP of inputs was taken from a variety of published sources such as the US Life Cycle Inventory (U.S. Department of Energy, 2015). Fuel consumption was used to determine the GWP of machinery and truck use for each operation. Heavy and light truck diesel consumptions were based on 2.5 and 4.2 $km \cdot L^{-1}$ (6 and 10 mpg), respectively. Published standards for diesel consumption by tractor horsepower, throttle, and load (Grisso et al., 2010) were used for each operation as previously reported (Hall and Ingram, 2014, 2015; Ingram, 2012, 2013; Ingram and Hall, 2013, 2014a). The GWP for gasoline and diesel consumption was determined based on "well-to-wheel" emission reported in GREET1_2011 (Vyas and Singh, 2011) as 2.9339 and 3.0153 kg CO_2e/L, respectively.

Landscape plants sequester carbon during production and during their useful life in the landscape. Carbon sequestration during production was estimated by washing, drying, and weighing four representative 5-cm-caliper trees (Ingram, 2012). Fifty percent of the dry weight was assumed to be carbon that resulted in 3.664 kg CO_2 uptake (U.S. Department of Agriculture Forest Service, 2008). The annual sequestration of red maple grown in a suitable lower midwest landscape for 60 years was estimated using the U.S. Forest Service's Center for Urban Forestry Research Tree Carbon Calculator calculation method (U.S. Department of Agriculture Forest Service, 2008). The impact on atmospheric CO_2 weighed over a 100-year assessment period was calculated as previously published for trees using PAS 2050 protocols (BSI, 2011; Hall and Ingram, 2014; Ingram, 2012, 2013; Ingram and Hall, 2013).

Results and Discussion

Tables 1 and 2 summarize the GWP and variable costs incurred at each stage of the life cycles for BNB and PIP red maple trees, respectively.

It is important to note that the trees produced using each production method are equivalent in size in spite of the difference in produce form (BNB vs. containerized). However, the total cost of the tree produced using the PIP production method is higher than for the BNB tree.

Effects of differences in cultural practices. In examining the major contributors to the PIP model system, the pine bark-based substrate and the no. 25 container contributed more than any other input product to the GWP of the PIP-grown tree (22% and 25%, respectively) (Table 3). However, the no. 25 container represented 21% of the total farm-gate variable cost, whereas the substrate only represented 7% of variable costs. Recycling and/or reusing a greater portion of the used containers could reduce the GWP. The liner also contributes significantly to the PIP cost (40%) and GWP (9%) of the final product and transporting the liner to the PIP nursery was a large component of the liner production model system. This means that the distance of liner transport would be a point of significant sensitivity in this model. Transport distance of the finished product to the customer is also an important factor in the GWP and variable costs but this process was only 45% as much as the GWP/km for transporting of BNB red maple as reported by Ingram (2012) and updated for a more inclusive fuel GWP and weighting carbon sequestration during production for a 100-year assessment period. GWP of the remaining production practices included 10% for fertilization, around 1.5% each for irrigation, staking and training, and harvesting, whereas insect and weed control only represented a little over 1% combined. The entire processes for harvesting, loading for shipment, transporting to the landscaper, and installation in the landscape accounted for 26% of the total cutting-to-landscape GHG emissions, and 35% of total variable costs. Although a total of 15.317 kg CO_2e would be invested from input materials, equipment use during PIP production and associated overhead activities, the growing tree would

Table 1. Summary of global warming potential (GWP) and associated variable costs incurred during the entire life cycle for a 5-cm-caliper containerized, pot-in-pot (PIP) red maple.

Component	GWP (kg CO_2e)	Variable cost ($)
Materials	0.0304	0.0711
Equipment use	0.0501	0.0804
Transportation of cutting	0.0000	0.0000
Labor	0.0000	0.1991
Nursery overhead	0.0009	0.0003
Subtotal: rooted cutting stage	0.0814	0.3511
Liner stage		
Materials	0.5141	1.6906
Equipment use	0.4245	0.3670
Transportation of liner	0.1585	0.2166
Labor	0.0000	3.6190
Liner nursery overhead	0.1813	0.0596
Subtotal: liner stage	1.2784	5.3856
PIP nursery stage		
Materials	13.0597	42.2365
Equipment use	1.9979	1.2855
Labor	0.0000	11.883
PIP nursery overhead	0.2595	0.0830
Subtotal: field stage	15.3171	55.4877
Weight sequestered in production	4.5750	
Total farm gate GWP and cost	10.7421	55.4877
Transport tree to customer	2.6268	3.4667
Transport tree to landscape	2.2837	1.9023
Planting in the landscape	0.0000	21.2010
Subtotal: postharvest stage	4.9105	26.5700
Total cutting to landscape	15.6527	82.0576
Weighted carbon sequestered: 901.3550 in landscape		
Take-down and disposal	214.2823	168.7067
Total life cycle GWP and cost	671.4200	250.7644

Table 2. Summary of global warming potential (GWP) and associated variable costs incurred during the entire life cycle of a 5-cm-caliper field-grown, balled and burlapped red maple.

Component	GWP (kg CO_2e)	Variable cost ($)
Materials	0.0040	0.0167
Equipment use	0.0086	0.0133
Transportation of cutting	0.0000	0.0000
Labor	0.0000	0.0684
Nursery overhead	0.0002	0.0000
Subtotal: rooted cutting stage	0.0128	0.0986
Liner stage		
Materials	0.0831	0.3381
Equipment use	0.2043	0.3622
Transportation of liner	0.1190	0.1625
Labor	0.0000	1.7531
Liner nursery overhead	0.0821	0.0261
Subtotal: liner stage	0.4885	2.6421
Field nursery stage		
Materials	3.6579	19.2008
Equipment use	12.2564	7.0906
Labor	0.00000	10.1586
Field nursery overhead	1.1588	0.2082
Subtotal: field stage	17.0730	36.6583
Weight sequestered in production	4.57500	
Total farm gate GWP and cost	12.4980	36.6583
Transport tree to customer	4.6560	6.2400
Transport tree to landscape	2.8544	2.3777
Planting in the landscape	0.9194	22.1499
Subtotal: postharvest stage	8.4298	30.7676
Total cutting to landscape	20.9278	67.4260
Weighted carbon sequestered: 901.3550 in landscape		
Take-down and disposal	214.2823	168.7067
Total life cycle GWP and cost	666.1449	236.1328

sequester an estimated 4.58 kg CO_2 (weighted for the 60-year life over a 100-year assessment period) (Table 1). Postharvest activities from the nursery gate to the landscape in this PIP model would emit 4.911 kg CO_2e and cost $26.570, 24% and 32% of total cutting-to-landscape GHG emissions and variable costs, respectively.

For the field-grown BNB trees, the major contributors to GWP and costs include the materials and equipment used during the harvest stage (Table 4). Harvesting accounted for 8.06 kg CO_2e/tree or 47% of the GWP investment during field production. Fertilization, weed management, insect management, irrigation, land preparation and planting, and staking and pruning accounted for 12%, 7%, 2%, 4%, 3%, and 2% of the GWP investment during field production, respectively. Although a total of 17.073 kg CO_2e would be invested from input materials, equipment use during field production, and associated overhead activities, the growing tree would sequester an estimated 4.58 kg CO_2 as described above. Therefore, field production processes and materials contributed a net of 12.50 kg CO_2e to GWP and $36.66 to variable costs of the product (Table 2). However, harvesting (10.280 kg CO_2e; $15.79) this BNB tree, transporting the finished tree 386 km to the customer (4.65 kg CO_2e; $6.24) and 32 km to the landscape site (2.854 kg CO_2e; $2.38), and equipment use in transplanting the tree (0.919 kg CO_2e; $22.15) contributed 73% of the cutting-to-landscape GHG emissions and 45% of variable costs. Transportation and transplanting of the finished BNB product in the landscape alone would contribute 8.430 kg CO_2e (34%) to the total GHG emission investment (25.503 kg CO_2e/tree).

Differences in shrink. The PIP system assumed shrink losses of 25%, 25%, and 10% for the cutting, liner, and field production stages, respectively. The BNB system, however, assumed 25% losses at the cutting and liner stages, but only 5% losses during production in the field. If the PIP system losses were reduced to half of those assumed, then farm-gate GWP and variable costs could be reduced 7.5% and 4.1%, respectively. On the other hand, reducing shrink by half for the BNB system would reduce farm-gate GWP and variable costs by 2.6% and 1.9%, respectively. Thus, the more expensive inputs associated with PIP production (e.g., liner, container, and substrate) causes that particular system to be more sensitive to plant losses.

Influences of crop timing differences. Essentially, the up-front components of the PIP system (e.g., system installation, plant container, liner, and substrate) represent 82% of the GWP as well as 81% of the total farm-gate variable costs. Thus, PIP growers must carefully consider the cash flow trade-offs associated with this system. This trade-off is offset in the BNB system with a substantial portion of the GWP and variables costs incurred on the back end of the system (60% and 43%, respectively). The liner and transplant activity for the BNB systems adds another 4% and 36% to GWP and costs, respectively.

Differences in crop timing should also be considered in a more dynamic longer-term nursery planning perspective. For example, a smaller liner is often planted when using a field production system and grown for more years until maturity vs. the PIP model system in which a larger (but more expensive) liner is purchased, requiring less time in the container. Some growers may opt to plant a slightly smaller liner to the PIP production phase and thus incur another year of growing time to reach the same saleable size. This saves on the initial cost of the liner, but adds

Table 3. Summary of global warming potential (GWP) and associated variable costs incurred during the field production stage of a 5-cm-caliper container-grown, pot-in-pot (PIP) red maple.

	Materials			Equipment Use			Labor	Total	
Activity/components	kg or unit/cutting	GWP (kg CO_2e)	Costs ($)	Hours/cutting	GWP (kg CO_2e)	Costs ($)	Costs ($)	GWP (kg CO_2e)	Costs ($)
PIP system installation	0.1378	0.3184	0.9435	0.0119	0.9610	0.4495	1.8913	1.2794	3.2843
Irrigation system installation	0.0017	0.0433	0.0000	0.0000	0.0000	0.0000	0.0000	0.0433	0.0000
Landscape fabric	0.8675	2.4029	1.2600	0.0000	0.0000	0.0000	0.0125	2.4029	1.2725
Insert/growing container	1.7000	3.8250	11.8500	0.0000	0.0000	0.0000	0.0000	3.8250	11.8500
Substrate	26.6394	3.3033	3.9683	0.0059	0.2603	0.1230	0.0827	3.5636	4.1739
Potting liners	1.1111	1.4204	22.0000	0.0178	0.0044	0.1727	2.0048	1.4248	24.1775
Transport containers to field	0.0000	0.0000	0.0000	0.0278	0.2109	0.1919	1.9578	0.2109	2.1498
Staking and training	1.1111	0.2020	0.8000	0.0000	0.0000	0.0000	2.9237	0.2020	3.7237
Irrigation	0.0000	0.0000	0.0000	0.8707	0.2159	0.0653	0.4277	0.2159	0.4930
Fertilization	1.1556	1.4515	1.1112	0.0000	0.0000	0.0000	0.0908	1.4515	1.2020
Apply herbicides	0.0044	0.0775	0.1246	0.0033	0.0000	0.0025	0.0470	0.0775	0.1741
Scouting and apply insecticides	0.0026	0.0154	0.1790	0.0011	0.0515	0.0674	0.2158	0.0669	0.4622
Transport from field	0.0000	0.0000	0.0000	0.0278	0.2109	0.1919	1.9578	0.2109	2.1498
Loading into truck/trailer	0.0000	0.0000	0.0000	0.0089	0.0829	0.0212	0.2707	0.0829	0.2918
Energy overhead					0.2595	0.0830		0.2595	0.0830
Total GWP and cost		13.0597	42.2365		2.2574	1.3685	11.8827	15.3171	55.4877

Table 4. Summary of global warming potential (GWP) and associated variable costs incurred during the field production stage of a 5-cm-caliper field-grown, balled and burlapped red maple.

	Materials			Equipment use			Labor	Total	
Activity/components	kg or unit/shrub	GWP (kg CO_2e)	Costs ($)	Hour/shrub	GWP (kg CO_2e)	Costs ($)	Costs ($)	GWP (kg CO_2e)	Costs ($)
Fallow year and land prep	0.0060	0.0243	0.0276	0.0104	0.4902	0.2773	0.1460	0.51451	0.45095
Sow row middles	0.0090	0.0364	0.0493	0.0009	0.0208	0.0128	0.0124	0.05721	0.07449
Transplant liners	1.0526	0.5142	12.6316	0.0059	0.1626	0.1331	0.5901	0.67679	13.35481
Fertilize	0.3999	1.8994	0.8111	0.0067	0.1036	0.1546	0.0950	2.00300	1.06063
Staking and training	0.0526	0.0838	0.0379	0.0262	0.3267	0.3126	2.2455	0.41046	2.59607
Irrigation	0.0000	0.0000	0.0000	0.0126	0.5978	0.0239	0.0445	0.59781	0.06845
Apply herbicide	0.0195	0.2239	0.3703	0.0063	0.1497	0.2301	0.0890	0.37358	0.68943
Apply insecticides	0.0077	0.0277	0.7030	0.0116	0.2744	0.5508	0.1632	0.30215	1.41704
Cultivate	0.0000	0.0000	0.0000	0.0168	0.3992	0.3303	0.2374	0.39919	0.56769
Mowing	0.0000	0.0000	0.0000	0.0126	0.2994	0.2065	0.1781	0.29939	0.38459
Digging	0.6634	0.8482	4.5700	0.0667	3.1948	1.5307	3.1952	4.04300	9.29586
Loading in field	0.0000	0.0000	0.0000	0.0500	2.2187	1.1230	1.2687	2.21867	2.39168
Hauling from the field	0.0000	0.0000	0.0000	0.0333	1.5775	0.9497	0.4699	1.57755	1.41955
Unloading and loading	0.0000	0.0000	0.0000	0.0500	2.2187	1.1230	1.2687	2.21867	2.39168
Removal of culls	0.0000	0.0000	0.0000	0.0066	0.2223	0.1322	0.1607	0.22226	0.29299
Energy overhead					1.1588	0.2082		1.15875	0.20822
Total GWP and cost		3.6579	19.2008		13.4151	7.2989	10.1644	17.07298	36.66413

another $2.79 to the costs of each tree and increases GHG emissions by 0.940 kg CO_2e. Similarly, a year longer in the field during the liner production stage would result in additional variable costs of $1.17 and increase GHG emissions by 0.233 kg CO_2e. Thus, growers can evaluate the trade-offs of cost and production times given these scenarios. A net present value analysis using a 20-year horizon would be appropriate for growers to use in analyzing these trade-offs for their own operations.

Postharvest comparisons. The two model systems developed from nursery manager interviews specify different average transport distances from the midwest U.S. nurseries for PIP (482 km) and BNB (386 km) trees and 125 more PIP trees on each load. Even with the shorter hauling distance in this model, the GHG emissions from transport and transplanting each marketable BNB tree of 8.430 kg of CO_2e was calculated to be 72% higher than the 4.911 kg of CO_2e for the PIP tree. The variable costs for transport and transplanting were $30.768 and $26.570 for the BNB and PIP tree, respectively.

Part of the value of developing models using these methods is that it allows for sensitivity to certain changes to be measured. For example, if 50 more PIP trees are loaded on each tractor-trailer, the GWP of 2.165 kg CO_2e and variable costs of $2.840 per tree would be smaller on a per unit basis than if 225 are loaded onto each tractor-trailer (GWP of 2.627 kg CO_2e and variable costs of $3.467). In the BNB system, only 100 trees are assumed to be loaded on each truck primarily because of weight and size restrictions. If 10 fewer BNB trees were transported on each truck, GHG emissions and variable costs would each be 11% higher per tree, to 5.158 kg CO_2e and $6.933.

Since the same-sized tree is ultimately planted in the landscape from either system, the same amount of weighted carbon is sequestered during the useful life of the tree. Take down and disposal GWP of 214.28 kg of CO_2e is incurred at a cost of $168.71 per tree. Thus, total system GWP and cost for the PIP tree system are –671.42 kg of CO_2e and $250.76, respectively, meaning that the tree sequesters much more carbon during its life cycle than is emitted. The same holds true for the BNB tree, however, in this system, the GWP of the tree –666.15 kg of CO_2e during its life cycle at a total variable cost of $236.14. Although the lifetime GWP impact for both trees is dominated by the sequestration of carbon during their useful lives, the BNB tree costs slightly less to produce than its PIP counterpart and the life cycle GWP is slightly less positive.

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 (grown using either method) more than offsets the amount of GHG that are generated during their production by the amount of GHG they sequester during their life span and this observation 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 overall nursery operation costs. Thus, a more efficient use of these environmentally sensitive inputs can not only reduce production costs for the nursery, but also reduce their environmental risks or impacts. 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 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 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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