Analysis of Production System Components of Container-grown 
Chrysanthemum for Their Impact on Carbon Footprint and Variable Costs Using Life Cycle Assessment

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Abstract. Life cycle assessment (LCA) was used to analyze the production system components of a 20-cm Chrysanthemum grown for the fall market in the north Atlanta region of the United States. The model system consisted of 2 weeks of mist in a greenhouse followed by 9 weeks on an outdoor gravel bed equipped with drip irrigation. The carbon footprint, or global warming potential (GWP), was calculated as 0.555 kg CO2e and the variable costs incurred during the modeled production system (from rooting purchased cuttings to loading the truck for shipment) totaled $0.846. Use of plastics was important in terms of GWP and variable costs with the container contributing 26.7% of the GWP of the product and 12.2% of the variable costs. The substrate accounted for 44.8% of the GWP in this model but only 12.1% of the variable costs. Consumptive water use during misting was determined to be 3.9 L per plant whereas water use during outdoor production was 34.8 L. Because propagation is handled in various ways by Chrysanthemum growers, the potential impact of alternative propagation scenarios on GWP and variable costs, including the purchase of plugs, was also examined.

Chrysanthemum L. grown for the fall market is a staple for many greenhouse and container nursery enterprises. Selection of cultivars to meet specific market demands and cultural limitations, such as the lack of infrastructure to provide short-day treatments, is possible given the immense array of available cultivars. Production systems without short-day treatments are often referred to as “natural-day” production. As is true for most floriculture and nursery crops, increased competition and decreasing number of potential wholesale buyers along with increasing cost of production require growers to analyze every aspect of their production system to increase efficiencies (Hall, 2010).

Life cycle assessment is a research tool that has been applied to the analysis of nursery crop (Hall and Ingram, 2014, 2015; Ingram, 2012, 2013; Ingram and Hall, 2013, 2014a, 2014b, 2015a, 2015b; Ingram et al., 2016, 2017a; Kendall and McPherson, 2012) and greenhouse crop (Ingram et al., 2017b, 2018) production system components to determine their contributions to the carbon footprint and variable costs of inputs and processes. Carbon footprint is expressed as the GWP of a product or process reflected in the emissions of greenhouse gases. GWP is calculated as the potential impact over a 100-year period of greenhouse gas (GHG) emissions, primarily carbon dioxide, nitrous oxide, and methane, using international standard procedures and reported as kilograms carbon dioxide equivalents (kg CO2e) (EPA, 2017; IPCC, 2006).

Materials and Methods

A production system model for Chrysanthemum in 20-cm containers was defined to reflect best management practices that were validated through grower interviews in the north Atlanta coastal region of the United States. The input products, equipment use, water use, energy inputs, and labor hours were inventoried and allocated for each operation in the production system. The system would consist of purchasing unrooted cutting and sticking one per 20-cm container directly in a peat and wood fiber substrate sometime between 26 June and 15 July depending on the target market and cultivar selection. It was assumed that natural day-length would stimulate timely flower initiation for this planting date range and cultivars selected. Following 2 weeks under mist in an unheated greenhouse, the plants would be moved to outdoor gravel beds and grown for an additional 9 weeks before shipping to market.

The outdoor beds would be covered with woven landscape fiber and gravel to a depth of 7.6 cm and projected to last 20 years. Their installation would require 5.4 h of a 29.8-kW diesel tractor at 50% throttle and 50% load with blade, 0.33 h of a 17.9-kW diesel tractor at 50% throttle and 50% load with a wagon and 4.26 h labor per A. A tank mix of preemergent and postemergent herbicides would be applied to the surface preseed annually at a combined rate of 11.406 kg a.i./ha.

The container would comprise high-density polyethylene and manufactured using a blow mold process similar to a Nursery Supply, Inc. (Chambersburg, PA) C350 with 20 cm diameter, 14-cm height, and a weight of 52 g. A mechanical system to mix the substrate components, fill the containers, and convey them through a potting line was
determined to require 15-kW of electric motors operating 0.125 h and use 3.578 h of labor per 1000 containers.

It was assumed that the 20-cm containers would be placed can-tight (0.041 m²/container) in a greenhouse with 75% space utilization, misted 3 s every 10 min for the daylight hours of 14 d, and delivered 3.9 L of water per plant. It would take 8.41 labor h and an electric cart (5.2 kW) for 0.42 h/1000 plants to move them from the greenhouse to the outdoor gavel beds and placed on 46-cm centers. A drip line with in-line emitters, manufactured from polyethylene and weighing 0.002 kg/m, would provide 63 irrigation events and deliver 0.553 L per container per irrigation and was assumed to be reused for three crops. A 14.9-kW electric pump would pressurize the line to 2200 plants at a time for 0.07 h/A/irrigation and an additional 3.7-kW pump would push water from a storage pond through a sand filter (Raudales et al., 2016). It was assumed that both pumps would run continuously during each irrigation event. Water-soluble fertilizer (15N–2.2P–12.4K) would be injected during each irrigation event at the rate of 100 mg N/L.

Fungicides (0.324 kg a.i./1000 plants) and insecticides (0.102 kg a.i./1000 plants) would be applied 10 times as a tank mix using a 3.74-kW sprayer for a total of 0.36 h and require 0.46 h of labor. A plant growth regulator (ethephon) would be applied two times for height control at a combined rate of 0.011 kg a.i./1000 plants and use a 3.74-kW sprayer 0.147 h with 0.2 labor h.

It would require 8.3 labor h and use a 5.2-kW electric cart for 0.412 h, to pull orders and 3.6 labor h to load 1000 plants on carts onto a truck for shipment. Based on previous studies (Ingram et al., 2017b, 2018) and grower interviews, 9.22 kWh of electricity and 0.104 m³ of natural gas were allocated to activities following international standards, prescribed previously for the functional unit.

Inventory analysis and data collection. LCA protocols were applied to the inventory of input products, equipment used, and other activities following international standards, including the International Organization for Standardization [ISO, 2006 (Geneva, Switzerland)] and PAS 2050 guidelines by BSI British Standards (2011). GHG emissions were determined for each input and activity, converted to kilograms CO₂e per functional unit, and summed. The functional unit was a natural-day mum produced and marketed in a 20-cm container. 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.

A GWP of each input product, including manufacturing processes and transportation, was calculated was published through SimaPro (Ecoinvent Centre, 2018) databases through SimaPro (Pre’ North America, Inc., Washington, DC). The GWP of natural gas combusted in an industrial boiler was established as 2.40 kg CO₂e/m³ and the GWP of electricity in the region would result in 0.853 kg CO₂e/kWh.

The substrate consisted of 60%40% by volume horticultural grade peat and wood fiber. A 10% shrinkage of the wood fiber when mixed with peat was assumed. Previous studies by the authors of this study used a GWP for a general peat class of 0.0226 kg CO₂e/kg from the USLCl database (U.S. Dept. Energy, 2018) and Ecoinvent (Ecoinvent Centre, 2018) databases through SimaPro (Pre’ North America, Inc., Washington, DC). In 2018, a GWP specific for horticultural grade peat from Canada was published through SimaPro as 1.08 kg CO₂e/kg or 47 times greater GWP compared with the previous GWP of peat used for a multitude of purposes, including as fuel.

A complete LCA analysis of wood fiber was conducted. Proprietary information on energy inputs, source of by-product materials, etc., was gained from a manufacturer of wood fiber and used to calculate a GWP of 0.363 kg CO₂e/kg of wood fiber. The analysis included transport of the raw wood by-product 120 km to the manufacturing facility and 0.21 kg of low-density polyethylene used to wrap each 0.085 m² bag of compressed wood fiber. The GWP of the combined peat and wood fiber substrate, including 1000 km transportation was calculated to be 1.18 kg CO₂e/kg, predominantly due to the horticultural peat. A peat/perlite substrate had a GWP of 0.309 kg CO₂e/kg, using the previously available GWP for peat (Ingram et al., 2018).

The GWP of applied NH₄NO₃, P₂O₅, and K₂O fertilizers were 9.7, 1.0, and 0.7 kg CO₂e/kg, respectively, as previously published (Snyder et al., 2009; Wang, 2007). A 1% loss of applied N as N₂O was assumed based on research with field soils and resulted in an estimated GWP of 4.65 kg CO₂e/kg of N applied (IPCC, 2006; Snyder et al., 2009; West and Marland, 2003).

Table 1. Global warming potential (GWP) and variable costs of production components (labor, materials, and equipment operation costs) incurred during outdoor production of 20-cm natural-day Chrysanthemum in the north Atlantic region of the United States.

| Activity/components | Materials GWP (kg CO₂e) | Costs ($) | Equipment use GWP (kg CO₂e) | Costs ($) | Labor GWP (kg CO₂e) | Costs ($) | Total GWP (kg CO₂e) | Costs ($) |
|---------------------|------------------------|-----------|---------------------------|-----------|-------------------|-----------|---------------------|-----------|
| Substrate components | 0.2111 | 0.2491 | 0.1162 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.2491 | 0.1162 |
| Mixing substrates and transplanting | 1.0101 | 0.0000 | 0.1539 | 0.0036 | 0.0020 | 0.0000 | 0.0000 | 0.0431 | 0.1971 |
| Transfers in outdoor bed | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0104 |
| Container | 1.0101 | 0.1485 | 0.1025 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.1485 | 0.1025 |
| Gravel bed with fabric | 0.5102 | 0.0627 | 0.0348 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0628 | 0.0375 |
| Irrigation/over management | 0.0005 | 0.0915 | 0.0540 | 0.0004 | 0.0051 | 0.0000 | 0.0000 | 0.0094 | 0.0187 |
| Fertilization | 0.0323 | 0.0595 | 0.0240 | 0.0004 | 0.0016 | 0.0000 | 0.0000 | 0.0021 | 0.0063 |
| Pest and weed management | 0.0011 | 0.0171 | 0.0292 | 0.0004 | 0.0016 | 0.0000 | 0.0000 | 0.0021 | 0.0132 |
| Plant growth regulator | 0.0001 | 0.0001 | 0.0030 | 0.0001 | 0.0006 | 0.0000 | 0.0008 | 0.0002 | 0.0060 |
| Pull orders and load truck | 0.0000 | 0.0000 | 0.0000 | 0.0004 | 0.0019 | 0.0000 | 0.0033 | 0.1432 | 0.0146 |
| Natural gas (overhead) | 0.0000 | 0.0000 | 0.0000 | 0.0001 | 0.0003 | 0.0000 | 0.0000 | 0.0003 | 0.0000 |
| Electricity (overhead) | 0.0000 | 0.0000 | 0.0007 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |
| Unallocated grower/labor | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0000 | 0.0051 | 0.0051 |
| Total per plant | 2.7765 | 0.5359 | 0.4765 | 0.0143 | 0.0194 | 0.0201 | 0.3497 | 0.5552 | 0.8462 |
The model was modified to examine the impact of a propagation phase in a 50-count tray to conserve greenhouse space or the purchase of rooted plugs to eliminate the propagation phase in this enterprise.

**Results and Discussion**

The GWP of natural-day mums in a 20-cm container, including input products and equipment use in all processes, was calculated to be 0.555 kg CO$_2$e (Table 1). The variable costs for this functional unit from rooting the cuttings (2 weeks) through outdoor production (9 weeks) and loading the trucks for shipment totaled $0.846. This compares with 0.140 kg CO$_2$e and $0.666$ for 11.2-cm begonias produced in the northeastern region of the United States (Ingram et al., 2018). The substrate components accounted for 44.8% of the GWP in this model but only 13.7% of the variable costs (Figs. 1 and 2). Horticultural peat comprised 92% of the GWP of the substrate. Similarly, fertilization contributed to a greater portion of the GWP (10.7%) than of variable costs (2.8%).

The purchased cutting and mixing the substrate, filling containers and sticking the unrooted cuttings in this model would contribute only 0.002 kg CO$_2$e to the GWP of the product whereas those activities contributed $0.197$ or 35.3% of variable costs, primarily because of the cost of the cutting ($0.153$) and labor requirements ($0.043$). Similarly, the cost of pest and weed management ($0.038$) was 4.4% of total variable costs but only 2.4% (0.013 kg CO$_2$e) of the GWP. Pulling orders and loading the truck contributed significantly to the variable costs ($0.146$; 17.3%) but were minor contributors to GWP. Transfer from the mist system in the greenhouse to outdoor beds added $0.101$ to the cost but had a negligible impact on GWP. Grower time not allocated to individual processes contributed $0.051$ to variable costs.

The container contributed to 26.4% of the GWP of the product and 12.1% of the variable costs. The use of plastic input products were also major contributors to GWP and variable costs for other model systems, including 11.2-cm begonia and #3 holly and boxwood (Ingram et al., 2016, 2017a, 2018). The gravel bed with woven fabric cover, spread over a 20-year life, accounted for 11.3% of the GWP and 4.4% of the variable costs. Energy overhead, application of plant growth regulator and water management were only minor contributors to GWP and variable costs.

Consumptive water use during misting was determined to be 3.9 L per plant whereas water use during outdoor production was 34.8 L. This compared with 1.8 L of water used for the production of a 11.2-cm begonia (Ingram et al., 2018) and 64 L per 72-count flat of foliage liners (Ingram et al., 2017b). Electricity for pumping irrigation water contributed only 0.005 kg CO$_2$e and cost $0.006$.

The scenario where cuttings would be rooted in 50-count trays before being transplanted into the 20-cm container would add the tray and extra substrate to the model, resulting in contributing 0.007 kg CO$_2$e to the GWP of the final product and costing an additional $0.033$. The process of sticking cuttings into the 50-count trays and increasing the transplanting labor by 25% for plugs compared with direct stick cuttings would cost an additional $0.020 per finished plant and add 0.003 kg CO$_2$e from equipment use. Misting the cuttings at the higher population per area would reduce water use by 3.6 L per finished plant, or 92%, and the reduced pumping requirement would decrease GWP by 97% to 0.0001 kg CO$_2$e and save $0.002$ per plant. The total impact of this scenario modification would add $0.055$ to variable costs and 0.010 kg CO$_2$e to GWP. Growers must weigh the costs and GWP affiliated with additional propagation inputs against the savings in greenhouse space during a time of the year in which space may be limited.
Purchasing plugs for direct transplanting into 20-cm containers would add to variable costs compared with the original and alternative propagation scenarios. Variable costs for purchasing unrooted cuttings and propagating them in the 20-cm container, not considering capital costs, would total $0.116 in this model compared with purchasing plugs for $0.375 each (or slightly lower if purchased in volume). However, a greenhouse would not be required for propagation. In this scenario, growers must weigh the convenience of buying in plugs versus the control (and potential costs savings) of producing their own.

Although the focus of this LCA was cutting to farm gate, assuming 4225 plants per tractor-trailer load and transporting 362 km, the GWP for this transport would be 0.102 kg CO₂e per plant. This would be 16% of the total 0.654 kg CO₂ GWP of the plant delivered to the market.

Growers seeking to reduce the carbon footprint of this product must consider the GWP of peat (1.08 kg CO₂e/kg) compared with the waterholding and aeration balance in plugs versus the control (and potential costs savings) of producing their own. In this scenario, including the waterholding and aeration balance in plugs versus the control (and potential costs savings) of producing their own.

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 and greenhouse operation costs. Thus, a more efficient use of environmentally sensitive inputs cannot only reduce production costs for the greenhouse but reduce their environmental risks or impacts as well.

In this study, LCA has been shown to be an effective tool for greenhouse growers in understanding the inputs, outputs, and impacts of production system components. It has also provided a linear time-oriented way of allocating costs to those systems. Information gained from this cost analysis and LCA can be used to determine the potential environmental impact factors and water footprint of field-grown tree production inputs and processes. J. Amer. Soc. Hort. Sci. 138:3–11.

Ingram, D.L. and C.R. Hall. 2013. Carbon footprint and related production costs of system components of a field-grown Cercis canadensis L. Forest Pansey identified during life cycle assessment. HortScience 49:1–6.

Ingram, D.L. and C.R. Hall. 2015. Carbon footprint and production costs associated with varying the intensity of production practices during field-grown shrub production. HortScience 50:402–407.

Ingram, D.L. 2012. Life cycle assessment of a field-grown red maple tree to estimate its carbon footprint components. Intl. J. Life Cycle Assess. 17:453–462.

Ingram, D.L. 2013. Life cycle assessment to study the carbon footprint of system components for Colorado blue spruce field production and landscape use. J. Amer. Soc. Hort. Sci. 138:3–11.

Ingram, D.L. and C.R. Hall. 2013. Carbon footprint and related production costs of system components of a field-grown Cercis canadensis L. ‘Forest Pansey’ identified during life cycle assessment. J. Environ. Hort. 31(3):169–176.

Ingram, D.L. and C.R. Hall. 2014a. Carbon footprint and related production costs of system components for a field-grown Viburnum x juddi using life cycle assessment. J. Environ. Hort. 32:175–181.

Ingram, D.L. and C.R. Hall. 2014b. Life cycle assessment used to determine the potential environmental impact factors and water footprint of field-grown tree production inputs and processes. J. Amer. Soc. Hort. Sci. 140:102–107.

Ingram, D.L. and C.R. Hall. 2015a. Carbon footprint and related production costs of pot-in-pot system components for red maple using life cycle assessment. J. Environ. Hort. 33(3):103–109.

Ingram, D.L. and C.R. Hall. 2015b. Using life cycle assessment (LCA) to determine the carbon footprint of trees during production, distribution and useful life as the basis for market differentiation. Proc. 1st Intl. Symp. Hort. Econ., Mktg. Consumer Res. 1090:35–38.

Ingram, D.L., C.R. Hall, and J. Knight. 2016. Carbon footprint and variable costs of production components for a container-grown evergreen shrub using life cycle assessment: An east coast U.S. model. HortScience 51:989–994.

Ingram, D.L., C.R. Hall, and J. Knight. 2017a. Comparison of three production scenarios for Buxus microphylla var. japonica ‘Green Beauty’ marketed in a no. 3 container on the west coast using life cycle assessment. HortScience 52:357–365.

Ingram, D.L., C.R. Hall, and J. Knight. 2017b. Modeling global warming potential, variable costs, and water use of young plant production system components using life cycle assessment. HortScience 52:1356–1361.

Ingram, D.L., C.R. Hall, and J. Knight. 2018. Global warming potential, variable costs, and water use of a model greenhouse production system for 11.4-cm annual plants using life cycle assessment. HortScience 53:441–444.

Intergovernmental Panel on Climate Change (IPCC). 2006. Guidelines for national greenhouse gas inventories. Volume 4: Agriculture, forestry and other land use. Chapter 11: N₂O emissions from managed soils, and CO₂ emissions from lime and urea application. 13 July 2017. <http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html>.

International Organization for Standardization (ISO). 2006. Life cycle assessment, requirements and guidelines. ISO Rule 14044:2006. Intl. Organization for Standardization, Geneva, Switzerland.

Kendall, A. and E.G. McPherson. 2012. A life cycle greenhouse gas inventory of a tree production system. Intl. J. Life Cycle Assess. 17(4):444–452.

Raudales, R.E., P.R. Fisher, and C.R. Hall. 2016. The cost of irrigation sources and water treatment in greenhouse production. Irr. Sci. 35:43–54.

Snyder, C.S., T.W. Brulsela, T.L. Jensen, and P.E. Fixen. 2009. Review of greenhouse gas emissions from crop production systems and fertilizer management effect. Agr. Ecosystem. Environ. 133:247–266.

U.S. Dept. Energy. 2018. U.S. life-cycle inventory database. National Renewable Energy Lab. (NREL). 13 Mar. 2018. <http://www.nrel.gov/environmental-systems/>.

U.S. Dept. of Labor. 2018. Wages in agriculture, 13 Mar. 2018. <https://www.foreignlaborcert.doleta.gov/adversecfm>.

U.S. Energy Information Administration. 2017. Maryland State Energy Profile. 13 Sept. 2017. <https://www.eia.gov/state/%20md/>.

Vyas, A. and M. Singh. 2011. GREET1.11 (Greenhouse gases, related emissions, and energy use in transportation). Argonne National Lab., Chicago, IL. 13 Nov. 2015. <http://www.anl.gov/environmental-systems/project/view-model>.

Wang, M.Q. 2007. GREET 1.8a Spreadsheet Model. 13 Nov. 2015. <http://www.transportation.anl.gov/modeling_simulation/index.html>.

West, T.O. and G. Marland. 2003. Net carbon flux from agriculture: Carbon emissions, carbon sequestration, crop yield, and land-use change. Biogeochemistry 63(1):73–83.

Yue, C., B. Campbell, C. Hall, B. Behe, J. Dennis, and H. Khachatryan. 2016. Consumer preference for sustainable attributes in plants: Evidence from experimental auctions. Agribusiness 32(2):222–235.

Zurko, J. 2016. Wage and benefit survey: Under the overtime rules. GrowerTalks 80(8):70–76.