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).

The production system for outdoor production of mums generally involves purchasing unrooted cuttings, rooting them under mist in a greenhouse, and growing plants outdoors in containers. Alternatives of this system would include purchasing rooted cuttings to forego the propagation phase in an enterprise, especially if greenhouse space is limited, and planting directly in production containers for outdoor production. Common sizes for this crop include 20- and 33-cm containers. The object of this study was to add information to an increasing database of GWP and variable costs for nursery and greenhouse model systems. A model system was defined and analyzed for natural-day mums in the north Atlantic region of the United States, grown for the fall market.

In addition to providing detailed impact information of the individual production system components so growers can find ways to increase production efficiency and minimize GHG emissions, information gained from these studies should be appealing to environmentally conscious consumers (BCG, 2009; Hall and Dickson, 2011; Yue et al., 2016).

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 4.266 labor h per A. A tank mix of preemergent and postemergent herbicides would be applied to the surface preseason 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 a 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

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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 0.022 kg·m⁻¹, 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 energy overhead for each 1000 plants. This allocation is in addition to the energy use calculated for individual operations described 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 from the U.S. life cycle inventory (USLCI) database (U.S. Dept. Energy, 2018) and Ecoinvent (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 USLCI database (U.S. Dept. Energy, 2018). 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 m³ 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).

Diesel consumption for each equipment operation was determined by tractor horsepower at designated percent throttle and load using published standards (Grisso et al., 2010) as previously reported (Hall and Ingram, 2014, 2015; Ingram, 2012, 2013; Ingram and Hall, 2013, 2014a, 2014b, 2015a). Gasoline and diesel consumption GWP was determined based on “well-to-wheel” emission reported in GREET1_2011 (Vyas and Singh, 2011) as 2.934 and 3.015 kg CO₂e/L, respectively. The GWP of fluids and lubricants used by equipment was calculated using GREET2_7 (Burnham et al., 2006) as previously reported (Ingram, 2013).

Labor does not contribute to a product's GWP; however, it does contribute significantly to variable costs. The adverse effect wage rate as determined by the U.S. Dept. of Labor (2018) was used to set the hourly wage rate of \$12.05 for this region. This represents the wage level that must be offered and paid to migrant workers by agricultural employers of nonimmigrant H-2A agricultural workers. The wage rate for growers/managers was established as \$24.04/h based on a published grower survey (Zurko, 2016). Labor requirements for operating equipment were calculated as 1.25 times the equipment operation hours to account for preparation and cleanup time. Equipment costs per hour were representative of those reported in regional enterprise budgets for horticultural crops (Betz et al., 2012). Natural gas and electricity prices for the north Atlantic region were established as \$0.151/m³ and \$0.0827/kWh, respectively (U.S. Energy Information Administration, 2017).

Alternative production strategies were also studied using the model developed.

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			Equipment use			Labor	Total	
	kg or unit per plant	GWP (kg CO ₂ e)	Costs (\$)	h per plant	GWP (kg CO ₂ e)	Costs (\$)	Costs (\$)	GWP (kg CO ₂ e)	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	0.0431	0.0020	0.1971
Transfers in outdoor bed	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.1014	0.0000	0.1014
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	0.0002	0.0004	0.0024	0.0628	0.0375
Irrigation/water management	0.0015	0.0043	0.0128	0.0004	0.0051	0.0059	0.0000	0.0094	0.0187
Fertilization	0.0323	0.0595	0.0240	0.0000	0.0000	0.0000	0.0000	0.0595	0.0240
Pest and weed management	0.0011	0.0117	0.0292	0.0004	0.0016	0.0021	0.0063	0.0132	0.0375
Plant growth regulator	0.0001	0.0001	0.0030	0.0001	0.0006	0.0008	0.0022	0.0007	0.0060
Pull orders and load truck	0.0000	0.0000	0.0000	0.0004	0.0019	0.0033	0.1432	0.0019	0.1465
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	0.0000	0.0092	0.0079	0.0076	0.0000	0.0079	0.0076
Unallocated grower/labor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0511	0.0000	0.0511
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 CO₂e (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 CO₂e and \$0.666 for 11.2-cm begonias produced in the north-eastern 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 CO₂e 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 CO₂e) 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 CO₂e 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,

Fig. 1. Global warming potential (GWP) for production components and activities for a natural-day 20-cm *Chrysanthemum* in the north Atlantic region of the United States.

Fig. 2. Variable costs for production components and activities incurred to produce a natural-day 20-cm *Chrysanthemum* in the north Atlantic region of the United States.

resulting in contributing 0.007 kg CO₂e 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 CO₂e 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 CO₂e and save \$0.002 per plant. The total impact of this scenario modification would add \$0.055 to variable costs and 0.010 kg CO₂e 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 CO₂e 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 other potential components such as pine bark (0.115 kg CO₂e/kg). However, there are many factors involved in such a decision including the waterholding and aeration balance critical for outdoor production with varying rainfall patterns.

Conclusions

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 of greenhouse production systems will help managers better understand the economic dimensions and potential environmental impact of their production systems and help them better articulate an improved value proposition for their plants in the green industry marketplace.

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