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Modeling Container-grown *Euphorbia pulcherrima* Production System Components: Impacts on Carbon Footprint and Variable Costs Using a Life Cycle Assessment

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***Abstract*. A model production system for a 15.2-cm poinsettia (*Euphorbia pulcherrima*) in the north Atlantic region of the United States was developed through grower interviews and best management practices and analyzed using a life cycle assessment (LCA). The model system involved direct sticking of unrooted cuttings. The propagation phase was 4 weeks, followed by 9 weeks of irrigation using a boom system and 4 weeks of flood-floor irrigation. The carbon footprint, or global warming potential (GWP), for the plant was calculated as 0.474 kg carbon dioxide equivalent (kg CO_2e), with a variable cost of $1.030. Major contributors to the GWP were the substrate and filling pots, fertilization, the container, irrigation, and overhead electricity. The major contributors to variable costs were the unrooted cuttings and labor to prepare and stick ($0.471). Furthermore, the substrate and filling containers and irrigation were notable contributors. Material inputs accounted for 0.304 kg CO_2e, whereas equipment use was estimated to be 0.163 kg CO_2e, which comprised 64.2% and 35.8% of total GWP, respectively. Material inputs accounted for $0.665 (64.6%) of variable costs, whereas labor accounted for 19.6% of variable costs for this model. Water use per plant was 77.2 L with boom irrigation for the 9 weeks during production spacing (32.8 plant/m^2) and represented 64% of the total water use. LCA was an effective tool for analyzing the components of a model system of greenhouse-grown, flowering, potted plants. Information gained from this study can be used by growers considering system alterations to improve efficiency.**

Fifteen program states are included in the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service (NASS) floriculture crop report, and ≈600 potted flowering plant growers surveyed in these states produce ≈$140 million of *Euphorbia pulcherrima* (poinsettia) annually (USDA-NASS, 2016). This model enterprise grew ≈32,000 pots in 2015; they were sold at an average price of $4.94 if grown in pots 12.7-cm or larger ($2.14 for those grown in pots smaller than 5 inches).

Profit margins have deteriorated for poinsettias because box stores have transformed this floral product from the specialty potted crop it once was (commanding premium prices) to a commodity crop sold at low prices to attract customers to stores (Hall, 2010). Because a portion of the poinsettia production cycle occurs during the most expensive time of the year to produce crops in the greenhouse, and because there is added cultural care needed to induce strong branching habits and coloration (to enhance shipability, shelf life, and visual quality), the profitability has decreased so much that many growers only grow them to make a contribution to overhead and/or keep their labor force employed year-round (Hall, 2010).

Despite these challenges, poinsettias remain a crop of considerable economic importance. Although consolidation within the industry has reduced the number of breeders, young plant producers, rooting stations, and growers, the green industry supply chain still depends heavily on this containerized flowering crop. A quick search for poinsettia-related research in the archives of *HortScience* and *HortTechnology* (183 articles in the past decade alone) attested to the continuing importance of this crop.

Considering the aforementioned competitive nature of the poinsettia market and the decreasing number of potential wholesale buyers that have resulted from retail-level consolidation, growers need to fully analyze every aspect of their production system to increase efficiency and decrease per-unit costs (Hall, 2010). Growers can often accomplish this by introducing lean manufacturing techniques to their respective value chains. However, recent literature also indicated the interconnectedness of efficient input use, cost savings, enhanced product quality, and sustainable nature of production or manufacturing practices (Boston Consulting Group, 2009). Sustainable practices are now viewed as profitable strategic imperatives to enhance profitability rather than mere environmental regulatory adherence (Rankin et al., 2011).

Measuring the sustainable nature of manufactured products is challenging, and live goods such as plants can be particularly perplexing; however, tools such as life cycle assessment (LCA) have been used successfully to map the entire supply chain for several sectors in the green industry. For example, LCA has been used for the analysis of production system components for nursery crops (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 crops (Ingram et al., 2017b, 2018a, 2018b) to determine their respective contributions to the carbon footprint and variable costs of inputs and processes in the green industry.

The carbon footprint is expressed as the global warming potential (GWP) of a product or process reflected in the emissions of greenhouse gases (GHG). GWP is calculated as the potential impact over a 100-year period of GHG, primarily carbon dioxide, nitrous oxide, and methane, using international standard procedures and is reported as kilograms of carbon dioxide equivalents (kg CO_2e) (IPCC, 2006; U.S. EPA, 2018).

The objective of this study was to contribute to the knowledge of greenhouse production systems by analyzing the environmental impact potentials of a model production system in the north Atlantic region of the United States for finished poinsettia plants in 6-inch (15.2-cm) containers. In addition to providing detailed information about the impact of the individual components

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of production systems so growers can find ways to increase production efficiency and minimize GHG emissions, the information gained from this study and others should be appealing to environmentally conscious consumers (Yue et al., 2016).

Materials and Methods

A model system for producing poinsettias in 15.2-cm containers was developed to reflect the current best management practices in the floriculture industry. Those practices and details of inputs and processes were validated through grower interviews in the north Atlanta coastal region of the United States. A life cycle inventory of every input product, equipment use, water use, consumed energy, and labor hours was created and allocated for each operation in the production system.

A poinsettia cultivar with an 8-week response time (time required from the beginning of short days to flower) was assumed. In this model system, unrooted cuttings purchased for $0.454 each (averaged from the online price lists) were stuck directly into production containers on 12 Aug. for a 1 Dec. market date. Flower initiation was expected to commence 6 Oct. with night-interrupting light provided 15 Sept. through 6 Oct. Plants were pinched once at 4 weeks after sticking (9 Sept.). The production timeline was assumed to consist of 4 weeks of propagation with a container density of 32.8 plants/m^2 and misting during 3 of those 4 weeks. Plants were moved to another greenhouse bay after those 4 weeks and spaced at a production density of 12.8 plants/m^2. During the last 13 weeks of the 17-week production cycle (week 32 to week 49), boom irrigation was used for 9 weeks and flood-floor irrigation was used for the final 4 weeks.

An 11.2-kW pump in the greenhouse was used to pump water from an underground storage tank for all irrigation. During misting, the pump was in use for 2.3 h and delivered 3300 L of water per 1000 plants. Boom irrigation during 1 week at high plant density required 0.86 h of pumping and delivered 1933 L of water per 1000 plants. Boom irrigation during spaced production plant density delivered 49,747 L of water, and the pump was in use for 4.05 h per 1000 plants for 50 irrigation events during this 9-week period. Flood-floor irrigation during the final 4 weeks of production required this pump to be in use for 0.87 h and pumped 89,375 L of water per 1000 plants. A 75% recycle rate for the flood floor was assumed; therefore, the total water use was 22,343 L per 1000 plants, assuming no evaporation from the enclosed tank. Water returning to the storage tank passed through filter paper dispensed from a roll at a cost of $0.034/1000 L.

In addition, a 14.9-kW electric pump maintained pressure in the main irrigation line for the entire greenhouse range, and a 3.7-kW pump pushed water from a reservoir through a sand filter (Raudales et al., 2017). It was assumed these supply pumps would run enough to supply the calculated irrigation volume of each production phase at 1514 L/min. Based on grower interviews in the region and previously obtained data (Ingram et al., 2016), in addition to electricity used to pump water, it was assumed that 0.89 m^3 of natural gas was consumed and 80 kwh of electricity was used per 1000 plants.

Water-soluble fertilizer (15N–2.2P–12.4K) was added to the irrigation water to maintain 120 mg N/L. For flood-floor irrigation, enough fertilizer was added between irrigations to apply 120 mg N/L to the 25% added and to replenish 25% of the fertilizer of the 75% irrigation water returned.

The container comprised high-density polyethylene and was manufactured using a blow-mold process similar to that of a C200 (Nursery Supply, Inc., Chambersburg, PA) with a 15.2-cm diameter, 15-cm height, and weight of 34 g. A substrate (60% horticulture grade peat: 40% wood fiber by volume) was mixed using a mechanical system powered by electric motors at 15 kW and was in use 1.8 h to fill 1000 containers. A four-person crew filled containers and transported those filled containers to the greenhouse bay at a rate of 5.13 laborer hours per 1000 plants. Unrooted cuttings were stuck in the filled containers in the greenhouse at a rate of 12/min/person. The model assumed a modern gutter-connected, Dutch-style greenhouse using natural ventilation with roof vents and retractable shade interior to the house using an integrated environmental control system. The roof and sidewalls were covered with bilayer polycarbonate, and the gutter height was 3.6 m.

In this model, a plant growth regulator such as Ethephon (2-chloroethyl) phosphonic acid was sprayed on the crop twice at 12.5 mL/L and 8.4 L of spray per 1000 plants, once before pinching and once after pinch. During propagation, eight applications of a tank mix of a fungicide (0.041 kg a.i./1000 plants) and insecticide (0.013 kg a.i./1000 plants) were performed. During production density, nine applications of the same tank mix of fungicide and insecticide were performed. Applications of the plant growth regulator and pesticides were performed using a 3.74-kW gasoline-powered sprayer for 0.03 h with 0.1 labor hour per application per 1,000 plants at high plant density and 0.2 h with 0.3 labor hours per application per 1,000 plants at production plant density.

Before plants were moved and spaced, plants were pruned/pinched using a mechanical device with rotary blades powered by a 3.7-kW gasoline engine running 0.09 h, and 0.36 labor hours per 1000 plants were invested to run the equipment and clean-up the clippings. This required 3.6 labor hours and used a 5.2-kW electric cart for 0.148 h to pull orders and 1.1 labor hours to load 1000 plants on carts and then on a truck for shipment.

Inventory analysis and data collection. The functional unit for this LCA was a poinsettia produced and marketed in a 15.2-cm container. Emissions from the manufacturing of capital goods, such as buildings and machinery, as per PAS 2050, Section 6.4.4, were not included in this study (BSI British Standards, 2011). LCA protocols were used for the inventory of input products, equipment used, and other activities following international standards, including the International Organization for Standardization (ISO, 2006) and PAS 2050 guidelines (BSI British Standards, 2011). GHG emissions were determined for each input and activity, converted to kilograms CO_2e per functional unit, and summed.

The GWP of each input product, including manufacturing processes and transportation identified in the LCA, was calculated. Sources of GWP information for input products and processes were taken from the U.S. life cycle inventory (USLCI) database (U.S. Department of Energy, 2018) and Ecoinvent (Ecoinvent Centre, 2018) database through SimaPro (Pre' North America, Inc., Washington, DC). The GWP of natural gas combusted in an industrial boiler was established as 2.40 kg CO_2e/m^3, and the GWP of electricity in the north Atlantic coast of the United States resulted in 0.853 kg CO_2e/kWh. Gasoline consumption GWP was determined based on "well-to-wheel" emission reported as 2.934 kg CO_2e/L in GREET1_2011 (Vyas and Singh, 2011). Gasoline consumption by the 307-kW engine for the sprayer was based on 1.25 L/h.

The GWP of the combined peat and wood fiber substrate was calculated as 1.18 kg CO_2e/kg, as previously published (Ingram et al., 2018b). Peat contributed 92% of the substrate GWP.

Based on previously published data (Snyder et al., 2009; Wang, 2007), the GWP values of applied NH_4NO_3, P_2O_5, and K_2O fertilizers were 9.7, 1.0, and 0.7 kg CO_2e/kg, respectively. Loss of N as N_2O was estimated as 1% based on research with field soils and resulted in an estimated GWP of 4.65 kg CO_2e/kg of N applied (IPCC, 2006; Snyder et al., 2009; West and Marland, 2003).

Although labor does not contribute to the GWP of a product, it does contribute significantly to variable costs. The Adverse Effect Wage Rate, as determined by the U.S. Department 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 clean-up 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 $0.151/$m^3$ and $0.0827/kWh, respectively (U.S. Energy Information Administration, 2017). The prices for the remainder of the production inputs used in the model production system that were included in the variable cost calculations were those for the 2018 calendar year.

Results and Discussion

The GWP at the farm gate for this model system for 17-week greenhouse production of 15.2-cm poinsettia in the north Atlantic region of the United States was 0.474 kg CO_2e per unit, and the variable costs was \$1.030 per unit (Table 1). The farm gate GWP and variable costs of a model system published for another potted flowering plant crop, 20-cm *Chrysanthemum*, were estimated as 0.555 and \$0.846 (Ingram et al., 2018b), and those for 11.2-cm begonia were 0.140 and \$0.666 (Ingram et al., 2018a).

Material inputs for the poinsettia crop accounted for 0.305 kg CO_2e, whereas equipment use, including greenhouse environmental control, was estimated to be 0.170 kg CO_2e (64.2% and 35.8%, respectively). Material inputs accounted for \$0.665 of variable costs, whereas equipment use, including greenhouse environmental controls, accounted for \$0.163, and labor accounted for \$0.201, reflecting 64.6%, 15.8% and 19.6% of variable costs, respectively.

In comparison, the input materials for the *Chrysanthemum* model system were 85.8% of the farm gate GWP and 56% of the variable costs; however, this was an 11-week crop from unrooted cuttings produced primarily outdoors during the warm months. Input materials accounted for 84.4% of the GWP and 82.5% of the variable costs of an 8-week from-plugs crop of greenhouse-grown begonia for the spring market. Labor costs for the *Chrysanthemum* model system and begonia model system were calculated to be \$0.350 and \$0.107, or 41.4% and 16% of the variable costs, respectively.

The clarity of these data for the poinsettia model can be optimized by defining activities that combine input material and equipment use for GHG impacts and these inputs plus labor for the variable costs of these activities (Figs. 1 and 2). The substrate components, mixing the substrate, filling containers, and placing the filled containers on the greenhouse floor accounted for 0.169 kg CO_2e (35.7%) of the farm-gate GWP, but only 12.8% of the variable costs. Sticking the unrooted cuttings in the containers after they were on the floor cost \$0.017 in labor.

The manufacturing and transport of the container accounted for 0.078 kg CO_2e of GHG, which was 16.6% of the farm-gate GWP and 6.8% of the variable costs. Fertilization contributed 15.4% of the GWP and 5.2% of the variable costs. Electricity in this model system accounted for 13.8% of the GWP and 6.2% of the variable costs, not including the GWP and cost of irrigation. Electricity comprised 1.4% of the GWP and 0.9% of the variable costs for the chrysanthemum model (Ingram et al., 2018b), and 12.4% of the GWP and 0.58% of the variable costs of the begonia model (Ingram et al., 2018a).

Table 1. Contribution of the model system components to farm gate global warming potential (GWP) and variable costs for production of 15.2-cm *Euphorbia pulcherrima* grown in the north Atlantic region of the United States.

	Materials			Equipment Use			Labor	Total	
Activity/Components	kg or unit/plant	GWP (kg CO_2e)	Variable Costs (\$)	h/plant	GWP (kg CO_2e)	Variable Costs (\$)	Costs (\$)	GWP (kg CO_2e) (\$)	Variable Costs (\$)
Substrate components	0.1263	0.1490	0.0695	0.0000	0.0000	0.0000	0.0000	0.1490	0.0695
Mixing substrates and filling pots	0.0000	0.0000	0.0000	0.0013	0.0204	0.0004	0.0619	0.0204	0.0623
Sticking cuttings	1.0100	0.0000	0.4545	0.0000	0.0000	0.0000	0.0169	0.0000	0.4714
Container	1.0100	0.0785	0.0697	0.0000	0.0000	0.0000	0.0000	0.0785	0.0697
Misting	0.0000	0.0000	0.0000	0.0023	0.0222	0.0271	0.0000	0.0222	0.0271
Boom irrigation	0.0000	0.0000	0.0000	0.0047	0.0450	0.0548	0.0000	0.0450	0.0548
Flood-floor irrigation	0.0004	0.0010	0.0031	0.0011	0.0122	0.0145	0.0000	0.0132	0.0176
Fertilization	0.0669	0.0731	0.0537	0.0000	0.0000	0.0000	0.0000	0.0731	0.0537
Pest management	0.0002	0.0029	0.0106	0.0003	0.0011	0.0014	0.0043	0.0040	0.0163
Plant growth regulator	0.0000	0.0001	0.0042	0.0000	0.0001	0.0002	0.0010	0.0002	0.0053
Pull orders and load truck	0.0000	0.0000	0.0000	0.0001	0.0007	0.0012	0.0562	0.0007	0.0574
Natural gas (overhead)	0.0000	0.0000	0.0000	0.0009	0.0021	0.0001	0.0000	0.0021	0.0001
Electricity (overhead)	0.0000	0.0000	0.0000	0.0769	0.0656	0.0636	0.0000	0.0656	0.0636
Unallocated grower/labor	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0610	0.0000	0.0610
Total per plant	2.2138	0.3045	0.6652	0.0877	0.1696	0.1633	0.2013	0.4741	1.0298

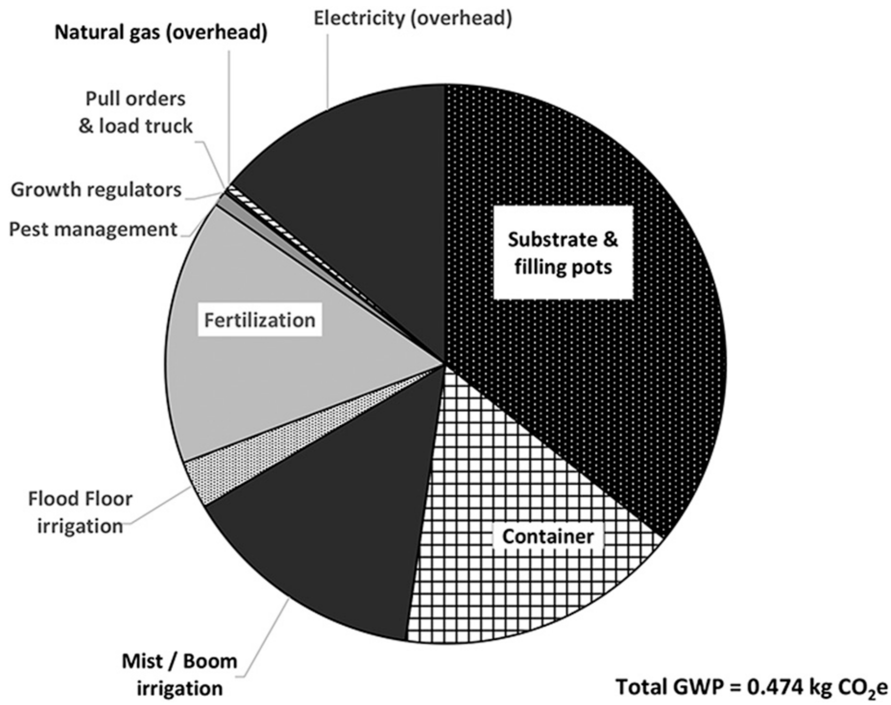

Fig. 1. Contribution of the model production system components to the global warming potential (GWP) at the farm gate for 15.2-cm *Euphorbia pulcherrima* grown in the north Atlantic region of the United States.

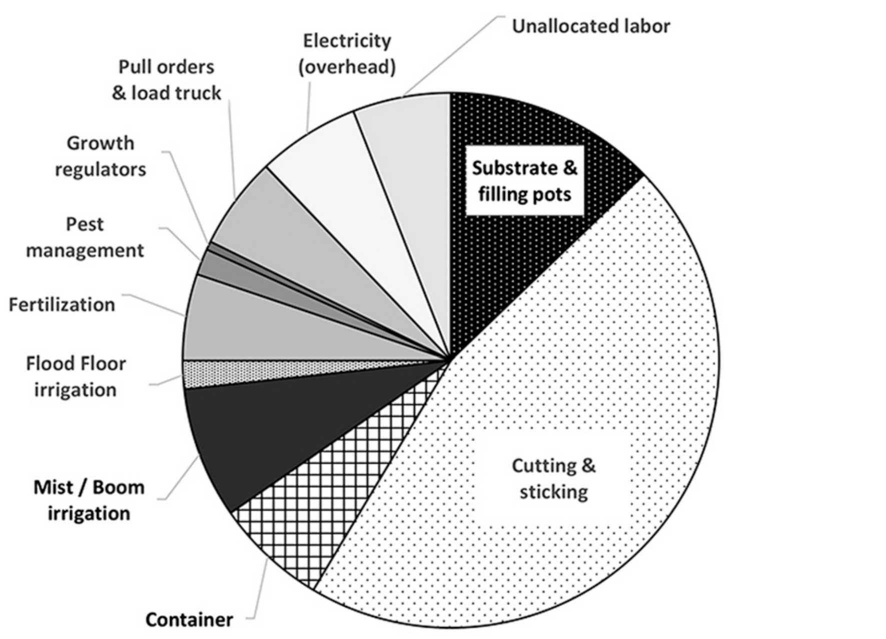

Fig. 2. Contribution of the model production system components to variable costs at the farm gate for 15.2-cm *Euphorbia pulcherrima* grown in the north Atlantic region of the United States.

Irrigation contributed 0.080 kg CO_2e (17.0%) of the GWP and 9.7% of the variable costs ($0.100). The GWP of irrigation stemmed mainly from the use of electric motors to pump water. The misting (3 weeks) and irrigation (9 weeks) using the traveling boom accounted for 83.6% of the irrigation GWP and 86.7% of the irrigation variable costs, whereas the flood-floor irrigation during the final 4 weeks of the crop accounted for 16.4% of the irrigation GWP and 13.3% of the irrigation costs. Flood-floor irrigation was used for 23.5% of the crop cycle; however, this was during the final stage when plants were larger and therefore required more frequent irrigation.

Water use for the system was 77.2 L per plant. The per-plant water use for misting was 3.3 L, boom irrigation at high plant density was 1.9 L, boom irrigation at production density was 49.7 L, and the flood-floor irrigation, including 75% recycled, was 22.4 L.

Pest management, plant growth regulators, pulling orders, and loading trucks were not important contributors to the GWP. However, the labor-intensive activity of pulling orders and loading trucks accounted for $0.057, or 5.6%, of variable costs. Unallocated labor for overall growing and management activities accounted for $0.061 (5.9%) of variable costs.

Using LCA to analyze components of a model system allows the construction of what-if scenarios that could aid in management decisions. Knowing that peat contributes 92% of the GWP of the substrate but only 21% of the variable costs would allow growers to make informed decisions about alternative substrate components. If fertilizer use was reduced by 10%, then the GWP of the plant would be reduced by 0.0073 kg CO_2e (1.5% of plant GWP), thus reducing the cost by $0.005 (0.48% of plant variable costs).

Purchasing unrooted cuttings ($0.454 each) and the labor required to stick those cuttings into containers after being placed on the greenhouse floor ($0.169) accounted for 45.8% of variable costs. The decision to purchase unrooted or rooted cuttings or to produce one's own is an important one. The availability of greenhouse space, labor, and expertise to produce cuttings are usually important considerations. Growers should analyze the trade-off of the potential return on the greenhouse space for those months compared with growing stock plants.

LCA is an effective tool for analyzing the production system components of a greenhouse-grown, flowering, potted plant. Understanding all the inputs, outputs, and processes and their impacts on the GWP and variable costs will allow growers to make informed decisions about their production systems. Knowing the GWP and variable costs will help managers position their products in the marketplace. Such marketing efforts focusing on the functional benefits of plants, rather than their mere aesthetic use, would likely be a more accepted proposition for the industry and should be emphasized in the future (Hall and Dickson, 2011).

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