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What Is a Carbon Footprint and How Does It Relate to Landscape Plants?

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Carbon footprint (CF) is a term used to describe the impact of greenhouse gas emissions associated with a product or activity. The objective of this publication is to enhance the reader's understanding of CF terminology and the science underlying its determination. Having such an understanding is necessary for managers and developers to minimize the negative environmental impacts of new product development and to assess positive or negative cradle-to-grave life cycle impacts. Life cycle assessment has been used to characterize the CF of representative field-grown and container-grown landscape plants.

If nursery and greenhouse crop growers and system managers know the input products and activities that contribute most toward CF and costs during plant production, they can more effectively make production protocol modifications that impact most on profit potential and environmental impact. Information about the economic and environmental life cycle benefits of these products can help marketers promote the purchase and use of landscape plants to environmentally conscious consumers.

Understanding Carbon Footprint

CF relates to the emission and removal of greenhouse gases in the environment. Carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4), the greenhouse gas emissions (GHG) that result from human and environmental processes, are of primary interest. These atmospheric gases warm the earth by absorbing energy and decreasing the rate at which energy escapes the earth's atmosphere to space. In other words, greenhouse gases increase the effectiveness of the atmosphere to act as a blanket that insulates the earth. Therefore, GHG have a measurable potential for trapping energy in the earth's atmosphere.

Greenhouse gases differ in their radiative efficiency or their effectiveness to absorb energy in specific wave lengths, primarily infrared. They also differ in terms of how long they stay in the atmosphere, or their lifetime in the atmosphere. Greenhouse gases have a global warming potential (GWP) that can be calculated based on their radiative efficiency and their lifetime. The greenhouse gas of greatest concentration is CO_2. The atmospheric concentration of CO_2 has been increasing, especially since the industrial revolution, and CO_2 remains in the atmosphere for thousands of years. Burning of fossil fuels has played a major role in this increase. To measure and describe this warming potential, GWP of emitted gases is expressed relative to the GWP of CO_2 for a 100-year period, or GWP_{100}. The GWP_{100} of CO_2 is set as 1 and serves as the reference to which other GHGs are compared and expressed.

The CF, or GWP, of a product or activity is expressed in kilograms of CO_2-equivalent (kg CO_2e). CH_4 and N_2O are estimated to have a GWP_{100} of 28 to 36 and 165 to 298 times that of CO_2, respectively. Animals, humans, natural wetlands, paddy rice fields, fermentation, and biomass burning release CH_4. Agriculture is a primary source of N_2O emissions, as are industrial activities, municipal waste landfills, and combustion of fossil fuels. Although found in the atmosphere at extremely low concentrations, gases such as chlorofluorocarbons, hydrofluorocarbons, hydrochlorofluorocarbons, perfluorocarbons, and sulfur hexafluoride can have GWPs thousands or tens of thousands of times greater than CO_2. These definitions were part of an international treaty, called the Kyoto Protocol signed in 1997 that was intended to reduce GHG, effective in 2005. Definitions and targets for reduction have been published on the Intergovernmental Panel on Climate Change (IPCC) website of the United Nations.

Life Cycle Assessment (LCA) is a research tool that has been developed over the years to estimate GHG during the life cycle of a targeted product or activity. This tool is accepted by the international scientific community, is governed by international standards, and has application to many fields, including agriculture. Under these standards, the LCA targets a well-defined functional unit, and all inputs for that unit are determined for the system. A functional unit may be anything from a quart of orange juice to a container-grown shrub or a field-grown tree. GWP is but one environmental impact that can be measured or estimated by LCA. Other potential environmental impact measures include water footprint, ecotoxicity, ozone depletion, acidification, and eutrophication. A complete cradle-to-grave life cycle assessment of a product or activity includes production, use, and post-life phases. However, a partial life cycle impact such as cradle-to-farm gate or seed-to-landscape can also be defined and analyzed.

Carbon Footprint of Landscape Plant Production Systems

The CF of the production systems for the major crop categories for landscape plants has been modeled (Table 1), including a field-grown shade tree (red maple [*Acer rubrum*]), field-grown evergreen tree (blue spruce [*Picea pungens*]), field-grown flowering tree (redbud [*Cercis canadensis* 'Forest Pansy']), field-grown deciduous shrub (juddi viburnum [*Viburnum x juddii*]), field-grown evergreen shrub ('Densiformus' taxus [*Taxus x media*]), pot-in-pot shade tree (red maple [*Acer rubrum*]), container-grown evergreen shrub on the U.S. mid-Atlantic coast ('Bennett's Compacta' Japanese holly [*Ilex crenata*]), container-grown evergreen shrub in the U.S. Pacific northwest region ('Green Beauty' boxwood [*Buxus microphylla japonica*]), herbaceous annual flowering plant (wax begonia [*Begonia x semperflorens-cultorum*]), young plants (foliage plants in 72-count trays), outdoor-grown flowering potted plant (chrysanthemum [*Chrysanthemum*]), and greenhouse-grown flowering potted plant (poinsettia [*Euphorbia pulcherrima*]). Those findings have been summarized in a *HortTechnology* review article by Ingram, Hall and Knight (2019). This LCA modeling research identified inputs and processes in these production systems that contribute the most to total CF and variable costs. Knowing the major contributors allows managers to strategically invest their time and resources in seeking alternatives that would make the greatest difference in environmental impact and profitability.

Field Production

Field production of trees and shrubs is still an important but decreasing portion of landscape plant production systems. Analysis of model systems for field-grown trees revealed that the farm-gate CF for 2-inch caliper red maple and blue spruce were 12.5 and 7.9 kg CO_2e, respectively (Table 1). The farm-gate CF for a 2-inch caliper flowering tree (redbud) was calculated to be 6.6 kg CO_2e. The variable costs were $37.74 and $36.66 for the field-grown red maple and redbud. It is important to note that 71 percent to 77 percent of the GHG for these field-grown tree model systems were due to equipment use and up to 89 percent of equipment use per plant occurred at harvest as shown in Figure 1. This should not be a surprise given that heavy equipment time was focused on individual trees for these operations. Input materials and equipment use in the harvesting process contributed an average of 26 percent of the total variable costs for field-grown tree models.

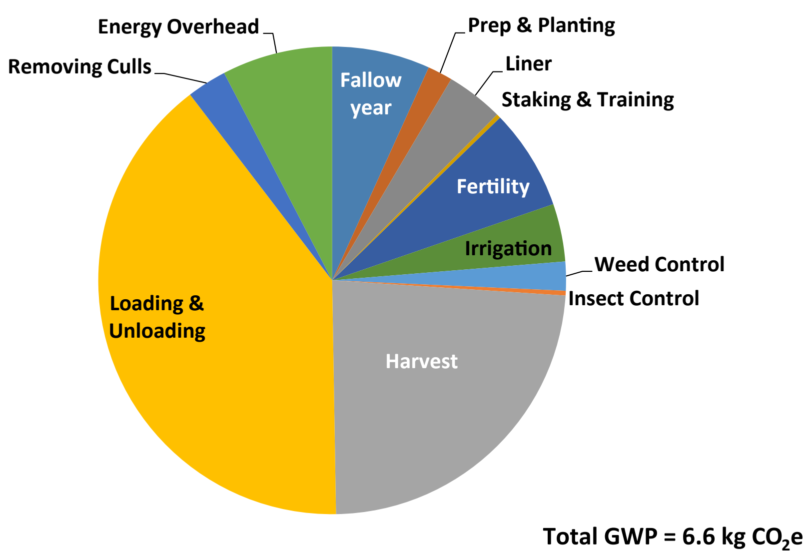
Field-grown shrubs are hand-dug and are grown on much higher density of plants per acre that for field-grown trees. The farm-gate CF for a 36-inch juddi viburnum was determined to be 0.70 kg CO_2e while the model system for an evergreen shrub, 24-inch taxus, utilizing a greenhouse propagation phase, was calculated as 0.77 kg CO_2e. Input materials accounted for more than 60 percent of CF for these field-grown shrubs while labor accounted for 71 percent to 77 percent of variable costs.

Table 1. Farm-gate carbon footprint (global warming potential [GWP], kilogram carbon dioxide equivalents [kg CO_2e]), and variable costs for landscape plant production models using life cycle assessment).

Plants modeled[z]	GWP (kg CO_2e)	Variable costs ($)
Red maple, B&B	12.5	36.66
Redbud, B&B	6.6	37.74
Blue spruce, B&B	7.9	--
Juddi viburnum, B&B	0.7	5.36
'Densiformus' taxus, B&B	0.77	5.09
Red maple, #25 PNP	10.74	55.49
'Bennett's Compacta' Japanese holly #3, U.S. mid-Atlantic region	2.14	3.22
'Green Beauty' boxwood #3, U.S. Pacific northwest region	1.72 – 3.36	2.88 – 5.73
4.5-inch wax begonia	0.14	0.67
Young plants tray (72-count)	2.28 – 4.22	24.86 – 25.25
8-inch chrysanthemum	0.55	0.85
6-inch poinsettia	0.47	1.03

[z] B&B = balled and burlapped from field production system; #25 PNP and #3 refers to industry standard container sizes; 4.5-inch, 8-inch and 6-inch refers to container diameter; 72-count refers to the number of plants in the tray. (For more information see Ingram, Hall, and Knight, 2019.)

Figure 1. Relative carbon footprint (global warming potential [GWP], kilogram carbon dioxide equivalents [kg CO_2e/tree]) of input materials and equipment use during redbud field production phase (seed-to-gate).



Container Production

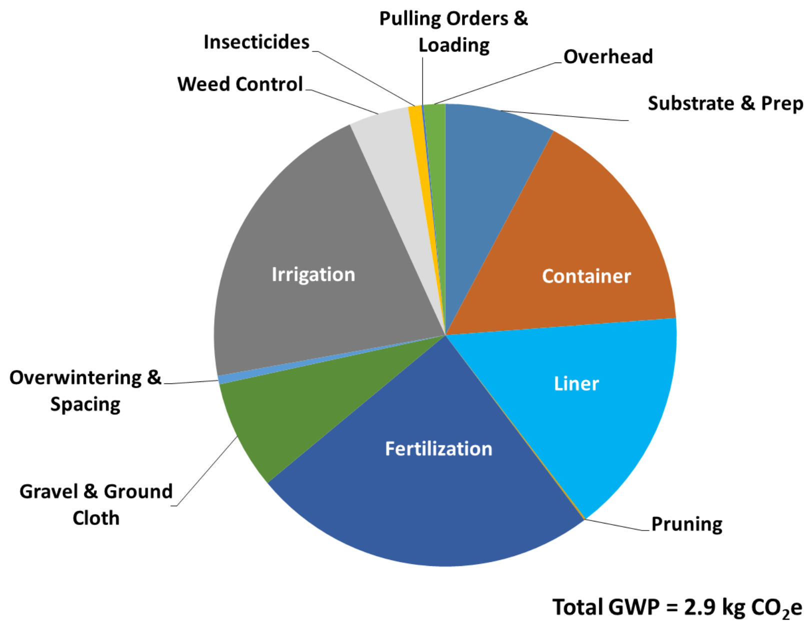
Container production has become the system of choice for growing and marketing most landscape plants. Most container-grown trees and shrubs are hardy in the climatic zone in which they are grown. They are grown on outdoor beds with full sun or artificial shade provided by shade structures. Winter protection of these plants is required in Kentucky to eliminate freeze damage to roots. The farm-gate CF of #3 container shrubs ranged from 1.72 to 3.36 kg CO_2e depending on the location and system protocols (Table 1). Variable costs for these shrubs ranged from $2.88 to $5.73, influenced primarily by input materials and secondarily by labor, both of which varied by container size sequencing practices.

A cutting-to-retail garden center study in California for trees in #5 and #9 containers reported CFs of 4.6 and 15.3 kg CO_2e, respectively. Direct fuel use contributed nearly 50 percent of the CF. Input materials, including the container, constituted the second largest contributor to CF.

The farm-gate CF for a 2-inch caliper red maple produced in a #25 container in a pot-in-pot production system in Kentucky was calculated to be 10.74 kg CO_2e, of which 85 percent was from input materials (Table 1). The insert or growing container contributed 30 percent of the input materials contributions to CF. Input materials contributed 76 percent of variable costs, influenced significantly by the cost of the liner.

While equipment use was the primary contributor to the farm-gate CF of field-grown plants, the use of plastics was the primary contributor for container-grown woody plants. A research team in Italy reported that use of plastics was a significant contributor to container-grown nursery crop CF. The CF of production system components for a #3 'Bennett's Compacta' Japanese holly in Figure 2 shows their relative impact.

Figure 2. Relative impact of production systems components of *Ilex crenata* 'Bennett's Creek' in a #3 container grown on the east coast of the U.S. on its cutting-to-gate carbon footprint (global warming potential [GWP], kilogram carbon dioxide equivalents [kg CO_2e/plant]).



Herbaceous annuals and flowering plants are primarily grown and marketed in containers. They are usually grown in greenhouses to satisfy spring or continuously available markets. Wax begonia produced in a greenhouse and marketed in a 4.5-inch container as part of a 12-plant shuttle tray was modeled (Table 1). The CF was calculated for this 8-week crop to be 0.14 kg CO_2e with variable costs of $0.67. Fifty-seven percent of CF and 43 percent of variable costs in the model were assignable to the container and shuttle tray. Interestingly, heating contributed little to CF or variable costs due to rapid turnover and a limited number of months requiring heat in this region. The CF of a greenhouse-grown poinsettia in a 6-inch container was modeled at 0.47 kg CO_2e, and variable costs were $1.03. The substrate, container, and fertilization contributed 30 percent of the CF. The unrooted cutting was 44 percent of the variable costs.

Young foliage plants in a 72-count propagation tray in a variety of greenhouse systems in the southern U.S. was estimated to have a CF of 2.28 to 4.22 kg CO_2e and variable costs of $24.86 to $25.25 (Table 1). Electricity and heating costs, even in the deep south, were the major contributors to CF (87% to 90%) for these tropical plants and micro-cutting and transplanting labor accounted for 77 percent of variable costs. Outdoor production of chrysanthemum in 8-inch containers was modeled to have a CF of 0.55 kg CO_2e with variable costs of $0.85. Although the container was an important contributor to CF, substrate components accounted for 45 percent of CF and 12 percent of variable costs.

Life Cycle Impact of Nursery and Greenhouse Plants in the Landscape

One of the life cycle benefits of landscape plants is their impact on atmospheric CO_2 during both the production and use phases. Although GHG occur during the production phase, CO_2 is sequestered from the air and stored in the wood of plants during production and their useful life in the landscape. CO_2 sequestered in wood it is not contributing to the atmospheric concentration, and therefore, not affecting GWP. Plants differ in terms of the density of their wood but approximately 50 percent of the dry weight of wood is carbon. A red maple in Kentucky is estimated to sequester 3632 kg CO_2 in a 60-year life. However, the 60-year life expectancy of a red maple is less than the 100-year assessment period and carbon sequestered in year 1 is held for 60 years but carbon sequestered in year 50 is only held for 10 years. Therefore, the impact of sequestered carbon on GWP in each year is weighted based on the portion of the 100-year assessment period. An example of the weighted impact of annually sequestered carbon by a red maple tree is shown in Figure 3.

Greenhouse gases will be emitted when the tree is removed from the landscape at the end of its life, primarily from gasoline and diesel combustion in chain saws, chippers, and trucks. GHG from take down and disposal were calculated to be 214, 148, and 88 kg CO_2e for red maple, blue spruce, and redbud, respectively. Take down and disposal of the shrubs studied would result in 1.25 kg CO_2e GHG.

The weighted positive impact on CF during the use phase is reduced to account for GHG during take down and disposal. The weighted life cycle CF of modeled trees and shrubs is presented in Table 2. In the case of the red maple, the weighted life cycle CF is –666 kg CO_2e; in other words this tree reduced atmospheric CO_2 and had a positive impact on the environment even considering GHG during take down and disposal (Figure 4).

The market for landscape plants has become more competitive in the recent decade and differentiation of one's business in the local market is an increasingly important business strategy. One way to differentiate a business is by adopting environmentally friendly behaviors and/or selling products that offer environmental benefits. Consumers' awareness and concern about environmental issues affect their purchasing habits

Figure 3. Carbon dioxide sequestration by a red maple tree during its 60-year life in the landscape weighted over a 100-year assessment period.

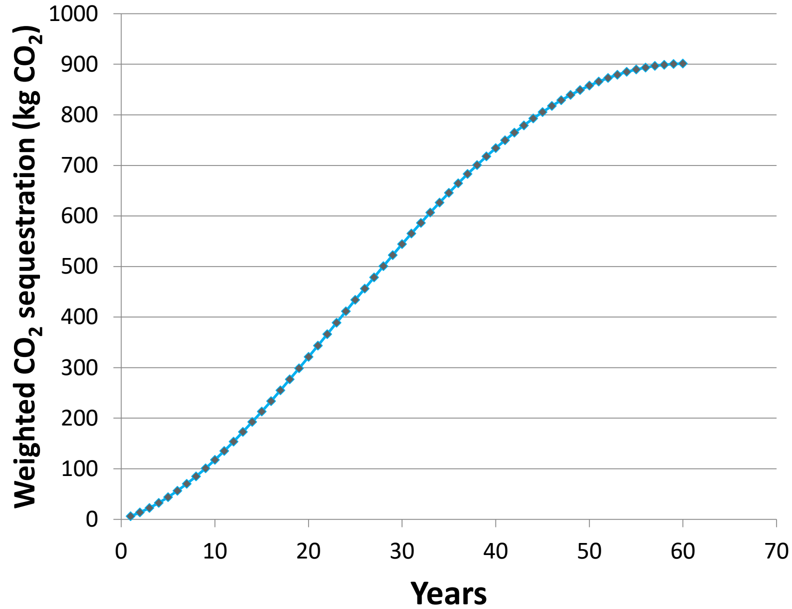
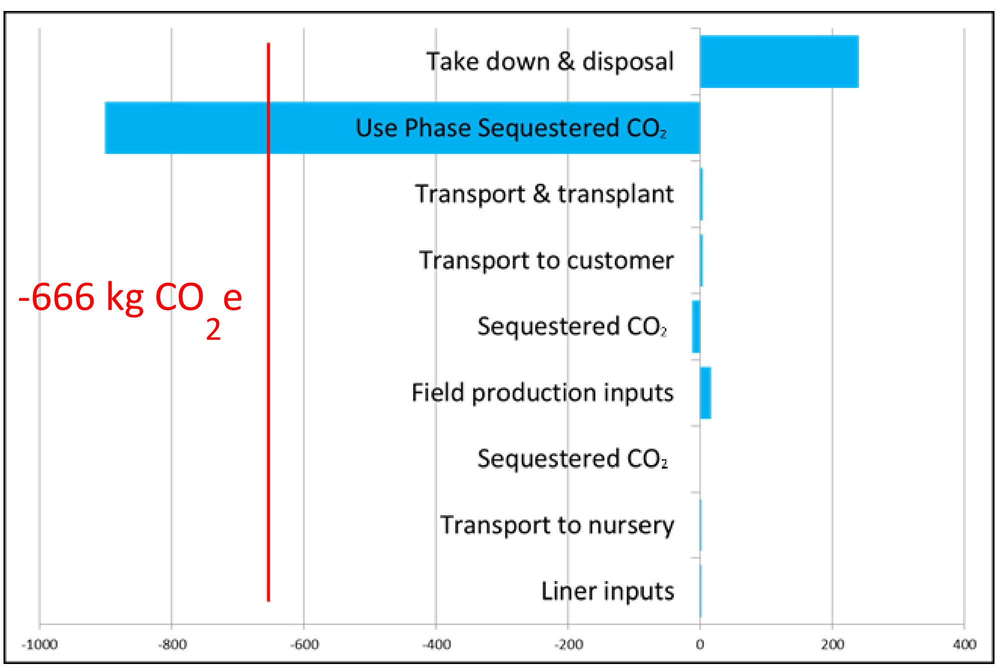


Table 2. The complete life cycle carbon footprint (global warming potential [GWP], kilogram carbon dioxide equivalents [kg CO_2e]) for woody landscape plant production and use models from propagation through disposal weighted as a portion of a 100-year assessment period using life cycle assessment.

Plants modeled	GWP (kg CO_2e)
Red maple	- 666
Blue spruce	- 430
Redbud	- 63
Juddi viburnum	- 11
'Deniformus' taxus	- 9

Figure 4. Life cycle impact of a red maple considering the carbon footprint (global warming potential [GWP], kilogram carbon dioxide equivalents [kg CO_2e/tree]) of production, transport, and transplanting, and take down and disposal balanced by the carbon sequestered during a 60-year life in the landscape, weighted over a 100-years.



and can reduce long-term adverse environmental impacts. The relationship between environmentally friendly business practices and consumer preferences suggests that nursery and greenhouse firms may realize financial benefits by producing and marketing environmentally sound products. In the current examples, planting shrubs and trees that more than offset the amount of GHG during their production by the amount of CO_2 they sequester during their life span could be emphasized in marketing efforts. Recent literature has substantiated that consumers increasingly consider the potential environmental impact of green industry products (e.g., carbon footprint) when making purchasing decisions.

This publication has summarized the life cycle impact of landscape plants on GWP by defining their CF. Herbaceous plant materials have minimal impact on GWP in the landscape; however, they contribute to environmental quality in other ways. Woody and herbaceous landscape plants provide many ecosystem services, including air quality improvement, microclimate enhancement, energy conservation, noise attenuation, and storm water management. They also contribute positively to human health and quality of life and increase property value.

Additional information about ecosystem services provided by landscape plants is summarized in University of Kentucky Extension publication *Ecosystem Services of Landscape Plants: A Guide for Green Industry Professionals* (HO-115), documented in other publications, and compiled online at ellisonchair.tamu.edu.

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