DIY Carbon Sequestration for Christmas Tree Growers

Written by: Stewart Cameron, University of New Brunswick

Contributions from: Matthew Wright, Canadian Christmas Tree Association
Bert Cregg, Michigan State University

Funded through: the Real Christmas Tree Board

Version 3.0 Jan. 2024

CHRISTMAS TREE CARBON LCA MANUAL

CONTENTS:

INTRODUCTION

Carbon is both accumulated and expended (emitted) during the process of growing Christmas trees. If a grower wishes, the carbon which flows into or out of their business, also called a life cycle analysis (LCA), can be calculated up until the trees leave the grower's hands and cease to be his/her responsibility. Cropping can be thought of as a type of biological carbon currency management, analogous in many ways to managing money. This manual and the accompanying spread-sheet provide some background, instructions, and calculations for Christmas tree carbon accounting.

The goal of this manual and spreadsheet is to provide a simple tool which will allow a grower to assess how their tree farming operation – and changes they may be contemplating to modify their practices – affect carbon sequestration: in other words, calculating a Christmas tree operation's "carbon footprint".

A carbon footprint is simply the shorthand term to describe an estimate of the full climate change impact of something. That something can be anything: an activity or an item, a lifestyle, a company, an industrial sector, or even a country. The carbon footprint is the simple way of referring to a carbon accounting standard initiated in the late nineteen nineties by two international associations, the World Resources Institute (WRI) and the World Business Council for Sustainable Development (WBCSD). The standard's purpose was to provide guidance to companies interested in determining their impact(s) on climate change and possibly decreasing their footprint.

The GHG accounting framework separates carbon emissions into three different "scopes" or categories. Scope 1 are the emissions from sources that a company owns or controls directly; scope 2 are emissions that arise indirectly from purchases of energy (e.g., electricity); and scope 3 covers all other indirect sources of emissions resulting from a company's business but no longer under the company's ownership or direct control (e.g., transportation and distribution of products after the point of sale). The carbon LCA program written here is compliant with Scope 1 and 2 emissions. It does not consider those in scope 3 in detail (with the exception of transport of harvested trees) which are more difficult to define and calculate. (Consult the website https://ghgprotocol.org/ for more information).

OBJECTIVES OF THE PROJECT AND SOFTWARE

The objectives set initially for the carbon LCA project were:

- To create a grower-focused, user-friendly tool intended solely for carbon sequestration, not wider sustainability or environmental impacts,
- A tool Intended specifically for Christmas tree growers, initially limited to field crops (not yet the nursery phase, though this may be added in a later version),
- Whenever possible, to use data of the types of crop records that growers might routinely keep for income tax or other purposes, such as fertilizer applications or fuel consumption.

The software itself has the following objectives:

- A user-accessible spreadsheet that does not require a commercial environmental or carbon sequestration package to provide supplemental data,
- A single printable one-page output summary of + and - contributions to net sequestration without inclusion of excessive detail.
- A tally sheet which a grower can use to enter the types of data, where possible, that ordinarily might be recorded during cultivation.
- A locked data sheet (not user accessible) where all constants, calculations and conversions to kg C or CO_2-eq are done.
- A user manual (this document) with details of the data entries required and explanations on how the spreadsheet uses it.
- Transparency: the effect of changing a data item in one work sheet in the spreadsheet can immediately be seen in the output spreadsheet.

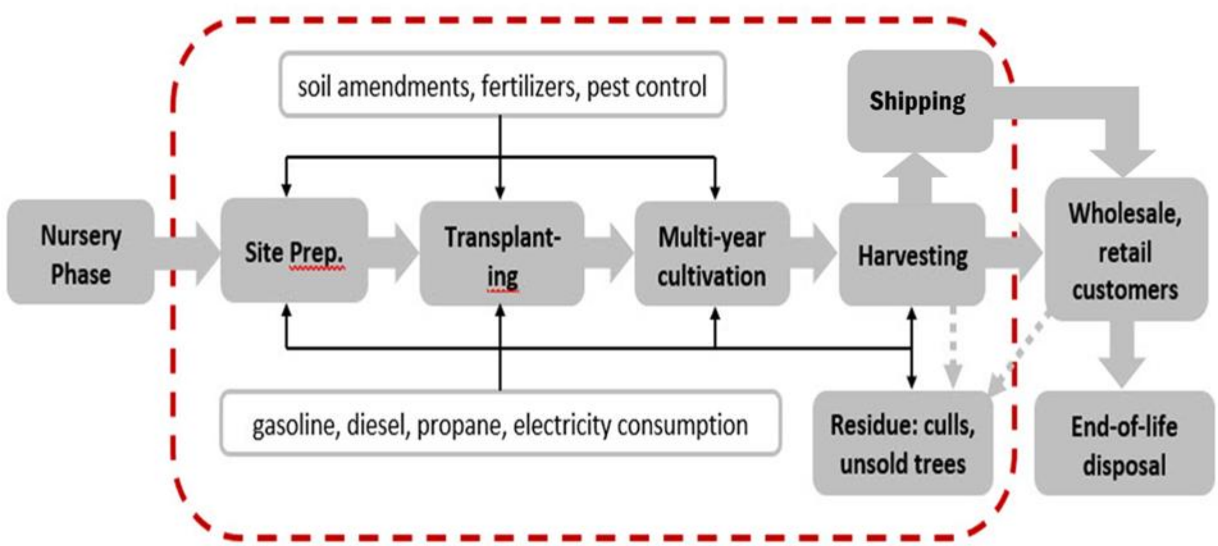
This spreadsheet's intended purpose is to be a tool for a Christmas tree grower who is interested in an approximate estimate of net carbon sequestration in his/her operation after various sources of carbon being input onto the site have been calculated. As noted above, the precision of the conclusions is limited by incorporation of a number of approximations, assumptions and omissions, some of which will be mentioned below in other sections of the text.

A number of approximations have been made and the LCA spreadsheet calculations are not intended to be exceedingly accurate. Many of the biological parameters are imprecise estimates only. For instance, the carbon composition of the woody components in a harvested tree can differ slightly from the values used, as does the carbon content of the dried tops and roots. Other times, practices that a grower may use (e.g., site preparation and CO_2 release from soil disturbances) have been intentionally ignored and not included due to the added complexity of calculating them and/or lack of standard data for doing so.

Other carbon LCA tools have been constructed in the past, often for farming, and mostly for annual crops. These alternatives are more complex, comprehensive (and expensive) software packages, not user-friendly and some of which require training, nor are they necessarily amenable for use by an individual grower.

THE BOUNDARY DIAGRAM

One useful way to visualize the scope of carbon LCA calculations is to draw a boundary diagram picturing the parts of a grower's operation which are to be included in the analysis. The diagram below displays the phases (in grey) and the inputs required (in the white rectangles above and below the phases) which are required for emissions calculations in this version of the spreadsheet. Initial nursery operations to provide planting stock are not included in version 3, nor are dispositions of harvested trees after being passed over to either retailers or wholesalers. If a grower retains and disposes of culls, the energy costs of doing so should be included in the LCA. Shipping by truck to a distant customer may or may not be part of a grower's LCA depending on the grower's orders.



The final aspects of the carbon flow – for instance, the end-of-life disposition is for a harvested tree once sold to, and disposed of, by a consumer – and therefore not decided by the grower – are not included. Culls and/or unsold trees retained by a grower are considered as largely carbon neutral (but only if mulched, chipped or buried), so only the additional fuel used for chipping needs to be included. (However, if residues are burned, they become an additional carbon emission if done as part of a grower's operation.)

This LCA includes only the phases of field growth and harvesting over which a grower has decision control (compliant with GHG Scope 1 or 2). The grower *must* have the power of choice over the entry and/or exit of carbon from their operation.

Note that this manual's use of the term "emissions" means emitting carbon to the atmosphere due to activities during the course of operating a tree farm – i.e., the opposite of trapping and thereby removing, or sequestering, carbon into the biomass of a growing crop of trees. Another way to put this is that carbon needs to be expended to grow a farmed tree (which then hopefully sequesters more carbon than is emitted in the process of doing so).

SPREADSHEET ENTRIES AND GROWER RECORDS

The boundary diagram helps to clarify the data that a grower needs to enter. To run the spreadsheet a grower is required to enter some of the data and/or records for their operation. No entries for specific years are required: only the accumulated total consumption of items like fuel(s), applications of fertilizers and/or pesticides summed over the years from the crop's planting to its harvest. All entries are put in one place: the Tally Sheet.

Many of the farm carbon emission sources – e.g., farm vehicles and motorized tools – may have uses on a farm for other crops or purposes in addition to the specific tasks involved with growing Christmas trees. If possible, to increase LCA accuracy a grower should attempt to determine (or estimate) the approximate percentage of items like fuels used for the Christmas tree operation as opposed to their uses for other operations and/or crops prior to entry into the Tally sheet.

To minimize a confusing format reported in version 2, in version 3 the spreadsheet has been rewritten in two separate versions: one for American growers in which the entries are in Imperial units (acres, US gallons, pounds etc.), and the other for Canadian growers where metric units are used.

Internal spreadsheet calculations (the sheet not visible to users) continue to use metric units, All the outputs displayed in the Summary sheet remain in metric units: carbon equivalents expressed as kg C/hectare.

Again, it is emphasized that only the summed cumulative totals which are required to operate the spreadsheet, regardless of which specific crop year the inputs actually occurred. ***NOTE: for routine use, it is suggested that a copy of the original spreadsheet should be made and renamed.***

CARBON SEQUESTRATION

Tree growth represents the sole source of the total (gross) amount of carbon sequestered. The boundary diagram above does not show the biomass of the harvested trees and the residual roots left behind. The carbon and other compounds (e.g., fertilizers) which directly or indirectly generate CO_2 are subtracted from the gross carbon captured in the biomass to calculate the net carbon sequestration.

This version of the spreadsheet does not have a place for other sources of carbon which a grower might add to their site (e.g., char or mulch). However, such additions would be straightforward to incorporate if they turn out to be a sufficiently common practice.

INITIAL PLANTING STOCK

It is assumed that the initial planting stock is an input of about 60 gm DWT per seedling which becomes incorporated as a very minor component in the biomass of the harvested tree, so the seedling DWT is not entered separately into the spreadsheet.

Actual dry weights greatly depend on the tree species being planted, nursery conditions, and grower preferences for initial stock size. Practically speaking, a 60 gm or other similar dry weight is not critical to sequestration calculations for a 7ft 6in tree weighing 10-20 kg DWT.

PROFILE OF THE PLANTED AREA

The Tally Sheet is where all tree data entered. Under the heading “TREE DATA” the first items required to begin the carbon sequestration analysis are:

- Selection of which Christmas tree species is being harvested. Only one harvested species entry per spreadsheet run is allowed at present, so the species choice is made by replacing the 0 in one of the boxes with a 1.

- For each harvested crop, the area initially planted (acres or hectares) and the number of seedlings planted, or alternatively, an estimate of initial stocking numbers in a natural stand.
- An estimate of the number of trees actually harvested compared to the initial number of seedlings planted. (Culls can be found by calculating the difference).
- The age of the crop in years at the last harvest, recognizing that trees may be harvested for more than one year off the same site. Currently, harvests of more than one species in the same year require a separate analysis for each one.

TREE DATA

Species:	USE "1" TO CHOOSE ONE SPECIES		
balsam fir	0	Hectares planted	Seedlings planted
Fraser fir	0		
Douglas fir	0	(1 ha = 2.47 acres)	
white spruce	0	Hectares harvested	Year(s) harvested
blue spruce	0		
Scots pine	0		
east. white pine	0		

The spreadsheet calculations are intended to apply ONLY to a single harvested acreage and the number of trees cut from it over one or more years. A separate analysis needs to be done for each planting or field, after which the individual sequestration analyses may be added together to describe the whole operation.

For example, if two hectares (4.9 acres) are planted with 7,000 seedlings in year 1, and subsequent operations are carried out (e.g., fertilizer and pesticide application, fuel, electrical use, etc.) identically on the whole two hectares. If half the site (e.g.,3000-3500 trees) is harvested at 8 years and the remainder of the trees are cut at years 9 and 10, the tally sheet could be used to enter the inputs and tree profiles after the final year of harvest – i.e., for all 7000 trees, or the total number that remain if some mortality has occurred during cultivation, from all three years' harvests.

Note: If several blocks or fields are planted, grown and harvested together, values for the individual blocks can be added together for the whole acreage as long as the blocks are treated identically.

PROFILE OF THE HARVESTED CROP

The next section of the Tally sheet is where a profile of the harvested trees at the end of the crop cycle is entered: species, heights, taper (expressed as a decimal fraction of height). The current software version can only handle one species at a time, though a range of heights can be entered.

An empty Tally sheet table is shown on the left, with a second example using dummy data in the box on the right-hand side. This example uses the decimal equivalents of standard tapers shown as examples in a box on the tally sheet. Growers may enter their own tapers as long as they are in decimal form).

Harvested Tree Profiles

Height in ft (m)	Number of Harvested trees at each height	Taper as a decimal
4.5 (1.37)	0	0
5 (1.52)	0	0
5.5 (1.68)	0	0
6 (1.83)	0	0
6.5 (1.98)	0	0
7 (2.13)	0	0
7.5 (2.29)	0	0
8 (2.44)	0	0
8.5 (2.59)	0	0
9 (2.74)	0	0
9.5 (2.90)	0	0
10 (3.05)	0	0
TOTAL	0	

Harvested Tree Profiles

Height in ft (m)	Number of Harvested trees at each height	Taper as a decimal
4.5 (1.37)	0	0
5 (1.52)	40	0.5
5.5 (1.68)	80	0.67
6 (1.83)	200	0.67
6.5 (1.98)	2500	0.67
7 (2.13)	500	0.67
7.5 (2.29)	100	0.67
8 (2.44)	50	0.67
8.5 (2.59)	0	0
9 (2.74)	20	0.4
9.5 (2.90)	0	0
10 (3.05)	0	0
TOTAL	3490	

The input sheet recognizes that trees of varying heights and perhaps differing tapers as well may be harvested from the same block, so multiple choices may be entered into the tally sheet.

The grower only needs to enter the number of harvested trees and their tapers for each height at 6-inch intervals ranging between 4 to 10 feet (1.4 to 3 meters).

The data sheet calculates a “cone” (using the formula for a cone’s volume – ⅓ π r2 h – where “h” is the height of the tree and radius “r” is ½ the taper value) describing the tree’s shape and volume. Therefore, using just the height and taper, the volume of a tree can be found for any combination of height and taper. The illustration below shows three trees of the same height but sheared to three different tapers: 60%, 75% and 95%, or 0.6, 0.75 and 0.95 respectively.

The idealized volume of the tree can be combined with its above-ground DWT to generate the “denseness” (analogous to density) of the above-ground biomass in kg DWT per m3. In the data sheet the kg DWT per m3 is an intermediate quantity used as part of the calculation to estimate the top dry weight of a tree of any size.

A series of data sheet calculation steps use the denseness to generate two quantities for all sizes of trees: an estimate of the total top DWT and the amount of carbon, expressed as kgC/kg DWT, which is the desired quantity.

To parameterize data sheet calculations real world data details of heights and tapers, plus dry weights for the needles, branches, and stems for seven different species of Christmas trees was provided by Bert Cregg of MSU and shown below. The individual trees measured at MSU were all approximately the same height: between 7 and 8 feet (2.14-2.44m). The MSU data indicates that the actual denseness varies from species to species (not shown), likely due in part to the differing proportions of needles, branches and stems among the seven species, plus variations in taper and, to a smaller degree, in height.

CHRISTMAS TREE SPECIES	Height (ft)	Cregg, MSU Dataset: Component DWTs (kg/tree)				Estim. Root DWT (kg/tree)	Dryad dataset (and others) Component %C Values				Estimated Total Tree C (kg C/tree)
		Needle	Branch	Stem	Top Total		Needle	Branch	Stem	Root	
Balsam fir	8.063	3.4935	2.548	1.7625	7.804	1.990	52.9	52.4	51.4	49.7	**5.078**
Fraser fir	7.317	3.709	2.276	1.575	7.56	1.928	52.9	52.4	51.4	49.7	**4.922**
Douglas fir	8.629	3.799	3.384	3.171	10.354	2.640	51.8	51.3	50.5	49.7	**6.617**
White spruce	7.120	2.452	2.524	1.682	6.658	1.698	54	52.7	50.6	49.7	**4.439**
Blue spruce	6.874	1.563	1.834	1.12	4.517	1.152	54	52.7	50.6	49.7	**2.950**
Scots pine	7.415	2.276	1.833	1.643	5.752	1.467	53.8	52.9	51.8	49.7	**3.774**
White pine	7.251	2.273	2.081	0.658	5.012	1.278	53.8	52.9	51.8	49.7	**3.300**

The carbon content of the MSU dry weight components (kg C/kg DWT) has been calculated separately for each tissue (needles, branches, stems, roots) by applying kg C/kg DWT data from the Dryad open-source database (accessible through datadryad.org) plus other references. Only the first (tree species) and last (kg C/whole tree) columns in the table above are used inside the data sheet.

RESIDUAL ROOT MASS

The fate of the post-harvest root biomass merits some explanation. Christmas tree root DWTs for trees of different sizes are not readily available from the literature and the dynamics of root deterioration are complicated. Therefore, changes in root DWTs and residual carbon have been estimated in a slightly different way. First, based on the Dryad data, the same kg C/kg DWT values (0.497 kg C/kg DWT) have been used for all root biomass estimates even though their lignin content varies slightly depending on the species and root type.

The stump and the two below-ground portions consisting of coarse and fine roots, remain behind as an important reservoir of sequestered carbon after the aerial portion of the tree is removed at harvest. In the published literature, young trees of several different conifer species at around age 7-10 years, have a root:shoot ratio on a DWT basis has been estimated at approximately 0.30, though the ratio can vary considerably due to variations in site quality and climate.

The coarse:fine root ratio in young trees is also quite variable but can be estimated at about 0.65. This is important because coarse root biomass is quite stable and degrades very slowly (measured at 0.2% per year). However fine roots, which are less lignified, degrade rapidly during the first year after harvest, and fine root decomposition at one year has been estimated at about 40% as measured in 7 different conifers (spruce, fir and Douglas fir, and pines) in one publication.

A very rough estimate, then, of the coarse+fine root biomass remaining after one year can be calculated as: top DWT (in kg) x 0.3 equals the total root biomass. 65% of the total biomass is coarse root mass and (0.60 x 35%), equal to 20%, is the residual fine root mass. The value for the total root mass remaining one year after harvest can then be calculated approximately as top DWT x 0.3 x (0.65 + 0.20) which equals 0.255 x top DWT. The post-harvest residual root DWT one year later may be multiplied by a published value of 49.7% as shown above to convert it to kg C/kg root DWT.

CARBON EMISSIONS

The boundary diagram denotes some of the main CO_2 emissions arising both directly from on-site fuel combustion and from a number of other sources like fertilizer applications (also called CO_2-equivalents). Other sources, as noted below, are currently not included. The main categories are as follows:

- Fuel consumption: amounts of diesel, gasoline, propane, LPG or natural gas estimated, or from field records of business expenses. Fuel used for post-harvest mulching or chipping should also be included.
- An estimate of electrical consumption (in KWH) allocated to the Christmas tree cropping operation, including both office lighting and at the point of retail sale, (if applicable).
- All nitrogen-based fertilizer applications with different types of fertilizer applied throughout the tree crop cycle.
- Different pesticide applications (insecticides, herbicides, fungicides) of all kinds. Only the total number of treatments for individual commercial products applied over the total cropping period are required. The software contains the calculated carbon contents at recommended application levels.
- Shipping of harvested trees by transport to distant customers. These fuel emissions are handled in a slightly different fashion. The mileage to all customer's or wholesaler's destinations is determined, then a standard of fuel consumption (miles per US gal, or liters per 100 km in Canada) for trucks is used to calculate carbon emissions.

SITE PREPARATION (not included)

Planting site disturbances of any kind release significant amounts of CO_2, but the estimation of how much is complex, and amounts vary greatly depending on the methods being used – e.g., ploughing/tilling emits CO_2 but the amount depends on soil type, soil N content and ploughing technique (conventional, partial, or no-till). Soil amendments (e.g., mulch, char if used) and herbicides also generate positive, neutral or negative after-effects.

Consequently, given the various methods that individual growers might use and the complicated calculations required, for the current version of the spreadsheet no estimate of the actual amount of CO_2 released through the many diverse types of initial site preparation is included. Only the amount of fuel used in site preparation is considered, which is counted elsewhere in the spreadsheet as part of total on-site fuel usage (see below).

FUELS and THEIR CO_2 EQUIVALENTS

All fuels used by a grower can be converted into units of kg of CO_2-eq and from there into kg C or carbon equivalents per unit of fuel consumed, regardless of the commercial fuel's type or unit of measure. The conversion factors quoted for various fuels in the table below are used within the data sheet to calculate the carbon inputs from the fuel usage the grower enters into the spreadsheet.

Note that the conversion of kg of CO_2 (kg CO_2 or kg CO_2-eq, where "eq" stands for equivalents) to kg of C (kg C or kg C) are easily converted back and forth: kg carbon to kg CO_2 = kg C x 3.67 and kg CO_2 to kg carbon = kg CO2 x 0.272.

Fuel	Liquid density	Specific CO2 or carbon emission per unit of fuel burnt				
	Kg/l	Kg CO_2/kg of fuel	Kg C/US gal of fuel	Kg CO_2/US gal of fuel	Kg C/liter of fuel	Kg CO_2/liter of fuel
Natural gas		2.75				
propane	0.510	2.99	1.57	5.78	0.45	1.67
LPG	0.537	3.01	1.66	6.12	0.41	1.51
Gasoline	0.737	3.30	2.50	9.20	0.66	2.29
Diesel	0.846	3.15	2.75	10.1	0.73	2.66

The correspondence of CO_2-eq to a fuel's carbon content is not strictly 1:1 since all fuels also emit minor impurities due to incomplete combustion and compounds like NO_x, N_2O ammonia and methane, some of which in comparison to CO_2 are even more potent greenhouse gases.

The units vary, but the total number of liters, US gallons or KWH consumed from the period between site preparation to harvest and disposition of culls is entered on the tally sheet. Fuel consumption data are converted to kg C/ha and summed inside the data sheet using the values in the Fuel table above, and total KWH values converted to k C/ha using Canadian or US kg CO_2-eq/KWH on are added.

FUELS					
for Canadian growers:		units	for US growers:		units
Natural gas	0	cu. m.	Natural gas	0	cu. ft.
propane	0	kg	propane	0	lbs
LPG	0	kg	LPG	0	lbs
Gasoline	0	liters	Gasoline	0	US gal
Diesel	0	liters	Diesel	0	US gal
Electricity	0	KWH	Electricity	0	KWH

Fuels for US and Canadian growers are handled in an identical fashion within the datasheet (other than US Imperial units being converted to metric units): where the acreage specified under "Hectares harvested" is used to convert from kg C/unit of whichever fuel is consumed to kg C/ha. Consequently, it is up to the grower to reduce the fuel consumption for their whole operation to a fraction of the total which can be allocated to just the harvested and then entering the fuel consumption values for just the particular harvested acreage.

ENERGY and CO_2 EQUIVALENTS

To incorporate electricity use, all processes and facilities required by a grower that require electrical power (e.g., office usage for administrative tasks, or perhaps light and heat in a family-run onsite retail sales site) also can be assigned carbon input values. While recognizing that an accurate estimate may be difficult, the grower should attempt to apply a reduction to total power billings to allocate only that portion of the total KWH consumed in their operation to the fraction applicable to the harvested acreage for the period between planting and harvesting. This reduced amount is the number of KWH that should be entered for the power used.

The CO_2-eq of electricity varies by region, primarily depending on source(s) of generation (e.g., hydroelectric power versus coal- or gas fired generation): country-wide consumption data provided for 2022 are Canada 0.128 kg CO_2/KWH and USA 0.367 kg CO_2/KWH (source: OurWorldinData.org), which converted to carbon equivalents would be 0.035 and 0.100 kg CO_2/KWH for Canada and the USA, respectively. These are the two values used in the data sheet.

FERTILITY

The amount and type(s) of nitrogen fertilizer used during cultivation is a major input source of CO_2-eq. Nitrogen-containing fertilizers also generate carbon equivalents as part of their environmental footprint during their commercial production and transportation. However, only their application to crop lands is considered here for carbon accounting since production and transportation to the farm gate are not usually directly under the control of a Christmas tree grower.

The topic of soil amendments and fertility, and the effects on carbon emission/ sequestration in an LCA is a large and complex topic. Much of the information is beyond the scope of data needed for the software inputs here, and major inputs other than fertilizers will not be considered for calculation of the impacts of their application in the current carbon LCA calculator version.

The impact of fertilization on a tree crop site falls into two broad categories: the application of ammonium nitrate fertilizer and the use of urea. The portion of any fertilizer containing N as NH_3 or NO_3 not absorbed by roots which remains in the soil is consumed in a complex process by a succession of soil microbes. They convert the ammonia to nitrite, then to nitrate and, finally, back to N_2, generating the potent greenhouse gas N_2O in the process. The data below which are used in the spreadsheet are adapted from a 2008 reference by Brentrup and Palliere titled "Energy Efficiency and Greenhouse Gas Emissions in European Nitrogen Fertilizer Production and Use".

FERTILIZER	%N	kg CO_2 /kg urea due to hydrolysis	kg CO2-eq /kg N due to N_2O emission
Ammonium nitrate	33.5%	0.00	1.26
Ca-ammonium nitrate	27 %	0.00	0.89
Ammonium sulphate	21%	0.00	0.98
Calcium nitrate	15.5%	0.00	0.65
Ammonium phosphates	18%	0.00	0.76
Urea	46 %	0.91	2.37
Urea ammonium nitrate	30 %	0.82	1.40
10-10-10 NPK	10%	0.00	0.37
15-15-15 NPK	15%	0.00	0.56

Nitrous oxide (N_2O) is the main non-carbon culprit. The various fertilizers are shown in the left-hand table column. Nitrous oxide (N_2O) emissions are shown in the righthand column converted to units of CO_2-eq per kg of N in the fertilizer. Therefore, the grower only needs to enter the fertilizer types and total amounts of each type in kg/ha in all fertilizer applications from planting to harvest. The kg C/ha values for all the different types of fertilizer used during cultivation are summed within the data sheet.

Liming with $CaCO_3$ was initially considered for inclusion because it generates CO_2 immediately upon application. However, there is an immediate soil interaction due to increasing pH which can decrease soil NO_2 emissions. The net effect on CO_2 production is not clear, so the effect(s) of liming are not included in the spread-sheet. Organic fertilizers – e.g., composted manure, humic acids etc. – are also complex and not included in this version of the spreadsheet but could be if requested.

SHIPPING

In both Canada and the USA many of the harvested Christmas trees are shipped by growers to remote customers by truck. Both countries also export large numbers of trees. Hauling over long distances is assumed to be done using either a 26 ft. box (panel) truck or a tractor-trailer, both of which use diesel fuel.

The exhaust CO_2 from long distance transport vehicles is considered to be a downstream GHG Scope 3 emission and must be accounted for in grower LCA calculations. Industry average fuel consumption values for panel trucks and tractor-trailers are 26.1 and 32.7 liters per 100km, respectively.

Both panel truck and tractor-trailer options are offered in the LCA Tally sheet. Distances to each individual customer may be easily found on sites like https://www.freemaptools.com/how-far-is-it-between.htm . For the year's shipped harvest, the grower puts the total summed number of highway miles or kilometers traveled to all customers for each type of vehicle (or both types, as required). In both versions the number of trees shipped is not required: only the total distances traveled in each of the two types of transport.

The requested input is in km traveled in the Canadian version:

SHIPPING (if used replace the 0 with total distance)

	Total km traveled
26 ft Panel Van (26.1 liters/100km)	0
Tractor-trailer (32.7 liters/100 km)	0

To convert distances into CO_2 values, one US gallon of diesel fuel generates 10.14 kg of CO_2, or in metric units, one liter of diesel creates 2.68 kg of CO2. All the necessary calculations are done within the Data sheet to combine the total distances driven by each vehicle type, their average fuel consumption values, and the unit values of CO_2 to produce a value expressed in kg C attributable to emissions from shipping the year's harvest. The final step converts the CO_2 emissions to kg C/ha by using the area harvested provided under "Tree Data".

HERBICIDES, FUNGICIDES, AND INSECTICIDES

The last carbon sources requiring grower inputs are for all pesticides used during the years between planting and harvesting the field of Christmas trees being cut.

Matthew Wright (CCTA) has provided a comprehensive inventory of herbicides, insecticides and fungicides as two separate lists currently registered for use with Christmas trees in either Canada or the United States. The chemical formulas of the active ingredients (A.I.) for the many organic compounds contained in the commercial products of this large dataset have been used to generate their equivalent carbon values applied on a sprayed area basis – i.e., kg of carbon sprayed per ha (kg C/ha). The calculated values for all pesticides registered in Canada are presented in an Appendix below as three tables – a herbicide, fungicide and insecticide table.

There is also a fourth table included for the small number of registered pesticides excluded for various reasons: the data per unit area could not be found or the use was not area-based (e.g., injectable compounds) and so was labelled "na" for "not available"; or compounds in which the A.I. contains no carbon (e.g., copper hydroxide), denoted by "0".

Note that many of the herbicides and pesticides also have other unspecified inert ingredients included as part of their formulations. Whereas the A.I.'s must be identified chemically on the product label, the percentage of total inert ingredient(s) – which can range from 0 to 99.9% – are only required to be specified, but not identified. However, inert compounds (e.g., "petroleum distillates") can contain C as well. In many instances an A.I. is only a small component of the commercial formulation, and the total C content, much of which may be contained in the inert compound(s), is almost certainly underestimated, and consequently, for many pesticides, the actual total amount of C applied per ha almost certainly is undervalued as well.

Depending on a grower's location, either the Canadian or the US listings on the tally sheet should be accessed. Like other items contained within the tally sheet, each of the three types of pesticides in the tables have fill-in boxes initially set to "0". The "0" may be replaced with a number to designate the number of times a particular pesticide has been used throughout the total period from planting to harvest of the trees.

Only the number of times a selected product was applied is required. Within the data sheet the number of treatments multiplied by their C/ha values are summed. Individual application rates do not need to be entered. The recommended application rates for the many different A.I.'s have been extracted from US EPA, Canadian or company literature and combined with the A.I. chemical formulas, then converted kg C/ha. The kg C/ha are shown as the final column in the commercial product listings in the Appendix at the end of the manual.

FINAL COMMENTS

To facilitate short printouts for record-keeping, both the Tally Sheet and the Summary page are formatted to fit on standard sized paper. If the complete list of pesticides (including the products used, indicated by a "1" next to the name) is not required, all other information is contained in first two pages of the Tally Sheet. The Summary sheet of results is a one-page printout.

A number of items – both C emission and C sequestration items – are not yet included in this version of the LCA spreadsheet. The reasons for doing so, often noted under some of the headings in the text above, vary widely. They may include any or all of insufficient or missing data; calculated impacts that are so small as to not make a difference (e.g., the carbon content of propylene binding twine or netting); or simply items that may have been overlooked in crafting the spreadsheet and manual. It is recognized that a Christmas tree grower does not have the time to routinely keep extensive eco-physiological records, so an attempt has been made to limit the inputs to the archived operational files growers might actually have on hand.

For most of the major C inputs (fuels, electricity, fertilizers, and pesticides) to reconcile the need for calculating the harvested acreage that may be less than the larger area(s) receiving the various input treatments, it is suggested that individual growers could generate a simple spreadsheet themselves. For all years from planting to harvesting the trees in a particular block, a 2-column record containing the harvested land area as a fraction of either the area of the total block under cultivation, or the total of all blocks in the operation in the case of fuel and electricity use, can be used as the multiplier to calculate the partial portion of inputs to allocate to the harvest in a specific year.   However, based on grower feedback, additional inclusions or changes may be written into future versions of the manual and spreadsheet.

APPENDIX: PESTICIDES REGISTERED IN CANADA

Can. Reg. Herbicide Name	Kg C/ha	Can. Herbicide Name	Kg C/ha
2,4-D Amine 600 Herbicide	0.211	Lontrel 360 Herbicide	0.057
Advantage Clopyralid 360	0.076	Lontrel XC Herbicide	0.056
Agrogill Oxyfluorfen 240EC	0.090	Nufarm Clopyralid Herbicide	0.057
Authority Supreme Herbicide	0.136	Poast Ultra Liquid Emulsifiable Herb.	0.308
Basket 2XL	0.090	Princep Nine-T Herbicide	1.681
BioLink Herbicide EC	0.036	Prowl H2O Herbicide	0.934
Broadstar	0.196	Pyralid Herbicide	0.084
Clip Herbicide	0.075	Rival	1.535
Clobber Herbicide	0.085	Simadex Simazine Flowable	2.341
Clopi Herbicide	0.047	Simazine 40 Herbicide	1.641
CT Mix 360 Herbicide	0.076	Specticle Flo Herbicide	0.048
Dual II Magnum Herbicide	0.870	Specticle G Herbicide	0.040
Dual Magnum Herbicide	0.870	Spinosad (Monterey)	0.115
Flazasulfuron 25WG Herbicide	0.014	SureGuard EZ Herbicide	0.115
Flumioxazin 51 WDG Herbicide	0.115	Sureguard Herbicide	0.076
Flumioxazin EZ Herbicide	0.115	Simadex Simazine Flowable	2.093
Frontier Max Herbicide	0.323	Thizzle Herbicide	1.562
Gallery 75 DF Herbicide	0.488	Treflan Granular Herbicide	1.581
Gallery SC Herbicide	0.488	Treflan Liquid EC Herbicide	0.433
Garlon XRT Herbicide	0.157	Triflurex 40 EC	1.850
GF-1966 Herbicide	0.271	Velpar DF VU Herbicide	0.149
GF-772 Herbicide	0.206	Velpar L VU Herbicide	0.206
Glyfos Soluble Conc. Herbicide	0.268	Venture L	0.090
Goal 2XL	0.090	VP480 Herbicide	0.014
Katana 25WG Herbicide	0.014		

Can. Reg. Fungicide Name	Kg C/ha	Can. Reg. Fungicide Name	Kg C/ha
Aliette WDG Systemic Fungicide	0.820	Echo NP Fungicide	0.915
Banner Maxx Fungicide	0.361	Equus 82.5 WSP	1.042
CGA279202 50 WG Fungicide	0.062	Flint 50WG Fungicide	0.062
Chipco Aliette	0.820	Forum Fungicide	0.172
Chlorothalonil 720F	1.079	Heritage Maxx Fungicide	0.491
Cyazofamid 400SC Fungicide	2.254	Medallion Fungicide	0.435
Daconil 2787 Flowable Fungicide	0.868	Rovral Fungicide Wettable Powder	0.413
Echo 720 Agricultural Fungicide	0.915	Subdue Maxx	0.185
Echo 90WSP Agricultural Fungicide	0.915	Torrent 400SC Agricultural Fungicide	0.839

Can. Reg. Insecticide Name	Kg C/ha	Can. Reg. Insecticide Name	Kg C/ha
415 Superior Spray Oil	1.973	Intrepid 2F	0.125
440 Superior Spray Oil	1.973	Invertid 2F	0.125
470 Supreme Spray Oil	1.973	Ipco Syncro Insecticide EC	0.017
Acora Insecticide	0.125	Lagon 480 E Insecticide	2.515
Acramite 4SC	0.302	Lesco Horticultural Oil Plus	1.989
Admire 240 Flowable Systemic	0.028	Magister SC Miticide	0.345
Akari 5SC Miticide/Insecticide	0.132	Mainspring GNL	0.216
Altus insecticide	0.200	Mainspring X	0.095
Ambush 500 EC	0.028	Malathion 500	0.399
Antixx Plus	0.066	Malathion 85E Insecticide	0.589
AzaDirect Botanical Insecticide	0.029	Malathion Liquid Insecticide - Miticide	0.399
BCS 2960 Insecticide	0.200	Matador 120EC Insecticide	73.680
Biocover LS	1.953	Merit 60 WP Gnhse&Nurs. Insec	0.118
Biocover MLT	1.953	Mimic 2 LV Speciality Insecticide	0.076
Biocover SS	1.953	Mite-E-Oil Insecticide - Miticide Spray	1.953
Biocover UL	1.953	Movento	0.243
Brandt Antixx Plus	2.777	Omite 30WS	1.225
Bug-N-Sluggo Insect, Slug, Snail Bait	2.777	Omite 6E	1.318
BYI 02960 200SL Insecticide	0.200	Omni Oil 6-E	1.953
Captiva	0.095	Onager	0.086
Captiva Prime	0.095	Orthene 75 %	0.147
Closer Insecticide	0.021	Orthene 97% Soluble Granule	0.343
Confirm	0.076	Perm-UP EC Insecticide	0.017
Conserve 480 SC Naturalyte	0.008	Pounce 384 EC Insecticide	0.017
Cygon 480 EC Systemic Insecticide	2.515	Pradia	0.203
Cygon 480 Systemic Insecticide	2.515	Purespray 10E	1.953
Damoil Dormant & Summer Spray Oil	1.953	Purespray 15E	1.973
Decis 100 EC Insecticide	0.013	Purespray Foliar 22E	1.973
Delegate Insecticide	0.053	Purespray Green	1.953
Demand CS Insecticide	0.017	Ripcord 400 EC	77.411
Diamante 4 Systemic Insecticide	2.515	RTSA Horticultural Oil	1.989
Diflumax 2L	0.057	Sarisa	0.126
Dimilin 25W IGR WP	0.057	Savey	0.364
Ecoworks EC	1.910	Seican	0.485
Endeavor 50WG Insecticide	0.107	Silencer 120 EC Insecticide	11.052
Entrust 80 Insecticide	0.008	Success Insecticide	0.008
Envidor 2SC Miticide	0.265	Sunspray Ultra-Fine Spray Oil	1.989
Flagship Insecticide	0.017	Talus	0.430
Floramite SC	0.096	TetraSan 5 WDG Miticide	0.098
Fyfanon 50 % EC	3.866	Tristar 70 WSP Insecticide	0.181
Glacial Spray Fluid	1.961	Tritek	1.594
Hexygon DF Miticide	0.364	Ultor	0.243
Hi-Supreme 440 Spray Oil	1.963	Ultra-Pure Oil Horticultural	1.953
IAP 440 Spray Oil	1.963	Vendex 50 WP Miticide	0.834
IAP Summer 415 Spray Oil	1.963	Warrior Insecticide	74.908
Intercept 60WP Greenhouse	0.118		

Can. Reg. Pesticides NOT Included in the Spreadsheet	Kg C/ha
HERBICIDES	
Finalsan Pro Commercial Conc.	na
FUNGICIDES	
Copper Spray WP Fungicide	0
Guardsman Copper Oxychloride 50	0
PESTICIDES	
Co-Op Malathion Liquid Insecticide	expired
Dipel 2X DF	na
Dursban Water Soluble Insecticide	canceled
Ecotec	na
Essentria All Purpose Insect Conc.	na
Foray 48BA Biological Insecticide	na
Gowan Cryolite Bait	0
Grandevo	na
Lorsban 4E	canceled
Mite-Phite ZM	0
M-pede	na
MPower Chloropyrifos Insecticide	canceled
ReVok Btk	na
Thuricide 48LV Biological Insecticide	na
Ultra Pure Oil	na
Venerate XC Bioinsecticide	na
Zelto	na