

Fertilization and Carbon Sequestration in BC Forests

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Trees sequester carbon as they grow by taking in carbon dioxide from the atmosphere and converting it into biomass. Fertilized trees grow faster because their increased foliage after nutrient update produces higher rates of wood growth. The BC Ministry of Forests and Range (MFR) currently projects a 15 cubic metre per hectare (m^3/ha) growth response to one fertilizer application by Interior spruce and Douglas-fir and a $30 \text{ m}^3/\text{ha}$ response by coastal Douglas-fir. That increased accumulated stemwood sequesters approximately an extra 13.8 tonnes of carbon dioxide (CO_2) per hectare for Interior forests and 27.5 tonnes on the coast.

This summary provides amounts of CO_2 produced through all stages of forest fertilization using urea, from fertilizer manufacture through to greenhouse gas emissions after application. Notes explaining the origin of the numbers are provided after the calculations.

Greenhouse Gasses Resulting from Urea Production, Transport and Application

Increased greenhouse gasses (GHGs) in the atmosphere produce climate change and are therefore being examined as by-products of forest management practices. Nitrous oxide and methane are two important greenhouse gasses and can be referred to in terms of carbon dioxide equivalent (CO_{2e}).

Fertilizer manufacture

The manufacture of each tonne of urea results in about 1.8 tonnes of CO_{2e} emitted to the atmosphere. A typical application rate in BC forests of 0.435 tonnes of urea/ha means about **0.8 tonnes of CO_{2e}/ha** is attributed to urea manufacture.

Fertilizer transport and application

Fertilizer transport requires an average of 5 litres of diesel per hectare fertilized, which produces **0.014 tonnes of CO_{2e}** . Fertilizer application requires 6 litres of aviation fuel per hectare fertilized. A helicopter engine burning 6 litres of fuel emits **0.016 tonnes of CO_{2e}** .

GHG emissions following fertilizer application

Using the IPCC (2006) guideline of 1% of applied nitrogen converting to nitrous oxide leads to the equivalent of **0.94 tonne of CO_{2e}/ha** being emitted as nitrous oxide (N_2O).

Total equivalent carbon dioxide emission

$0.8 + 0.014 + 0.016 + 0.95 = \mathbf{1.79 \text{ tonnes of } \text{CO}_{2e}/\text{fertilized hectare}}$

The ratio of carbon sequestered by the stemwood of fertilized trees to the amount of greenhouse gas released into the atmosphere through all stages of forest fertilization:

- For Interior forests with an average growth response of $15 \text{ m}^3/\text{ha}$:
Carbon stored/Carbon emitted = approximately $13.8/1.79 = \mathbf{7.7}$
- For coastal forests with an average growth response of $30 \text{ m}^3/\text{ha}$:
Carbon stored/Carbon emitted = approximately $27.5/1.79 = \mathbf{15.4}$

NOTES

These explanatory notes provide background information for the calculations shown on page 1.

1) Carbon Sequestration

Carbon sequestration by the bole of a tree can be approximated as 0.25 tonne of carbon per cubic metre of wood (W. Kurz, pers. comm.). This is calculated using the weight of a cubic metre of wood equal to about 0.5 tonnes, and wood is about 50% carbon. Wood growth in the bole of a tree may be a conservative estimate of overall ecosystem carbon sequestration as it ignores any extra carbon (C) stored in the litter and soil. However, balancing that is the fact that BC commercial softwood trees have a density averaging a bit less than 0.50 tonnes/cubic metre.

The BC MFR currently projects a 15 cubic metre (m³) per hectare (ha) response to fertilization by Interior spruce and Douglas-fir, and a 30 m³/ha response by coastal Douglas-fir. The relationships of 1 m³ of wood containing 0.25 tonnes of C and 1 tonne of stored carbon removing 3.67 tonnes of CO₂ from the atmosphere leads to 13.75 tonnes of CO₂/ha sequestered in Interior fertilized forests (15 m³/ha * 0.25 tonne/m³ * 3.67) and 27.5 tonnes/ha of CO₂ sequestered in coastal forests (30 * 0.25 * 3.67).

2) CO₂ Generation in Urea Manufacture

The amount of carbon dioxide emitted in urea production is not straightforward. Various reports provide different CO₂ emission factors. Different organizations have set different standards on when carbon is counted and where and by whom it is accounted. The accounting differences appear to be caused by different interpretations of life cycle analysis and placement of portions of the CO₂ sources and sinks. Emission factors may also vary due to the efficiency of manufacturing plants caused by age of technology (older vs. recent) and the source of fuel and feedstock (e.g., natural gas vs. coal).

Several CO_{2e} emission factors for the production of urea fertilizer are reported in Table 6 of Wood and Cowie (2004). The reported factors are in units of g CO_{2e}/kg urea fertilizer. The emission factors vary widely based on different reporting procedures, and range from 420 to 1848.

For this summary, the CO₂ credited in urea manufacture is excluded as it is returned to the atmosphere promptly after urea application. The lower emission factors appear to credit carbon storage in urea. Since the CO₂ is released upon hydrolysis of the urea after application, it is not credited to urea production to avoid having to count urea as a source of the same CO₂ following application. The higher figure of 1848.7 g of CO_{2e}/kg urea fertilizer (1.8487 kg) is used for the following calculations. The amount of CO_{2e} emitted to produce urea for 1 hectare is determined as follows:

- The application rate of urea is typically 435 kg/ha.
- The amount of CO_{2e} emitted to produce 435 kg urea is: 435 kg urea multiplied by 1.8487 kg CO_{2e}/kg urea = 804 kg of CO_{2e}.
- 804 kg CO_{2e} = 0.8 tonnes of CO_{2e}

3) Fertilizer Transport and Application

Fertilizer transport requires approximately 5 litres of diesel per hectare^a

	Emission Factor (EF)^b (g/l fuel)	g/ha (5 * EF)	CO_{2e}^c Factor	CO₂ Equivalent (g/ha) (g/ha * CO_{2e} factor)
CO ₂	2730	13,650	1	13,650
CH ₄	0.12	0.6	25	15
N ₂ O	0.082	0.41	298	122
Total				13,787

CO₂ g/ha = 5 litres/ha * 2730 g/l = 13,650 g/ha

13,787g/1,000,000g/tonne = **0.014 tonnes**

Fertilizer application of 6 litres of aviation fuel per hectare^d

	Emission Factor (EF)^b (g/l fuel)	g/ha (6*EF)	CO_{2e} Factor	CO₂ Equivalent (g/ha) (g/ha * CO_{2e} factor)
CO ₂	2550	15,300	1	15,300
CH ₄	0.080	0.48	25	12
N ₂ O	0.23	1.38	298	411
Total				15,723

6 l/ha * 2550 g CO₂/l = 15,300 g CO₂/ha

15723g/1,000,000 g/tonne = **0.016 tonnes**

Sources

a) USFS, 1982

b) Emission factors from Environment Canada, 2005

c) Forster et al., 2007

d) Ron Gladiuk, Western Aerial Applicators, pers. comm., May 2008

Note that the relative carbon dioxide emission from transporting and applying the urea is very small compared to the amount of carbon dioxide emitted during urea manufacture.

4) GHG Emissions Following Fertilizer Application

The IPCC report (2006) suggests that 1% of the applied nitrogen (N) will become N₂O. One percent of 200 kg N/ha is 2 kg N/ha. Using the ratio of 1:1.6 for N to N₂O from the chemical composition means that 3.2 kg of N₂O results from the application of 200 kg N/ha. The CO₂ equivalent, in terms of global warming potential, of nitrous oxide is 298 times that of CO₂.

Therefore, 3.2 kg N₂O is equivalent to 298 times 3.2 kg CO₂ = 953 kg CO_{2e}, and 953 kg CO_{2e} = 0.95 tonnes of CO_{2e}.

The IPCC estimate of N₂O emission following N application has an uncertainty range of up to 3%. Using 3% instead of 1% in the calculations has the following results. Three percent of 200 kg N/ha is 6 kg N/ha. Using the ratio of 1:1.6 for N to N₂O means that 9.6 kg of N₂O results from the application of 200 kg N/ha. The CO₂ equivalent, in terms of global warming potential, of nitrous oxide is 298 times that of CO₂. 9.6 kg N₂O is therefore equivalent to 298 times 9.6 kg CO₂, which equals 2861 kg CO₂. 2861 kg CO₂ = 2.86 tonnes of CO₂.

Using 2.86 tonnes of CO₂ for total equivalent carbon emission per hectare:
 $0.8 + 0.014 + 0.016 + 2.86 = 3.69$ tonnes of CO₂. Then, for a growth response of 13.8 tonnes of CO₂ /ha, Carbon stored/Carbon emitted = approximately $13.8/3.69 = 3.74$.
And for a growth response of 27.5 tonnes of CO₂ /ha, Carbon stored/Carbon emitted = approximately $27.5/3.69 = 7.4$.

References

- Environment Canada. 2005. National Inventory Report, 1990-2005: Greenhouse gas sources and sinks in Canada. Available at http://www.ec.gc.ca/pdb/ghg/inventory_report/2005_report/a12_eng.cfm#a12_1_4.
- Forster, P., V. Ramaswamy, P. Artaxo, T. Berntsen, R. Betts, D.W. Fahey, J. Haywood, J. Lean, D.C. Lowe, G. Myhre, J. Nganga, R. Prinn, G. Raga, M. Schulz and R. Van Dorland. 2007. Changes in atmospheric constituents and in radiative forcing. *In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group 1 to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M. Tignor and H.L. Miller (eds.)]. Cambridge Univ. Press, Cambridge, UK and New York, NY, USA.
- Intergovernmental Panel on Climate Change. 2006. Guidelines for national greenhouse gas inventories. Chapter 11: N₂O Emissions from Managed Soils, and CO₂ Emissions from Lime and Urea Application. Available at http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_11_Ch11_N2O&CO2.pdf.
- USFS. 1982. Environmental assessment of aerial fertilization project, Gifford Pinchot National Forest. Exhibit 6: Fertilizer-related energy output/input ratio (Appendix). 45 pp.
- Wood, Sam and Annette Cowie. 2004. A review of greenhouse gas emission factors for fertiliser production. For IEA Bioenergy Task 38. Cooperative Research Centre for Greenhouse Accounting. Research and Development Division, State Forests of New South Wales. June. Available at www.ieabioenergy-task38.org/publications/GHG_Emission_Fertilizer%20Production_July2004.pdf.

Conversion Factors

4 m³ wood sequesters approximately 1 tonne of carbon
Ratio of CO₂ to carbon is 44:12 = 3.67
Ratio of carbon to CO₂ is 12:44 = 0.273
1 litre = 0.264 gallon (US)
One gallon (US) = 3.785 litres