LCA of Value-Added Novel Bio-products Processing and Production

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Introduction

Growth in the Canadian organic agriculture and landscape horticulture industries, as well as increasing public environmental awareness, and concerns with negative environmental impacts from conventional agricultural and landscape horticulture production systems have prompted a need for more environmentally-sustainable production systems and practices (Allen and Kovach 2000; Daigle and Gautreau-Daigle, 2001). Peat-based bioproducts have been widely used as growing media and soil amendments in both the agriculture and horticulture industries, and in establishing and maintaining landscapes (World Energy Council, 2007). However, there are growing concerns with long-term sustainability of peat moss reserves in Atlantic Canada (Poulin et al., 2004), and negative environmental impacts from harvesting and processing peat (Roulet, 2000).

Increasing global demand for peat has also resulted in depletion of the resource in Atlantic Canada (Poulin et al., 2004), resulting in increasing peat product prices (Nappi and Barberis, 1993), and deterioration in peat quality, partly because even carefully restored peat land often cannot regenerate the original peat bog (Alexander et al., 2008). Governments and municipal authorities in Canada are encouraging the agricultural and landscape horticulture industries to use increasing proportions of peat alternatives, with total replacement of peat as a long-term goal.

In addition, a consequence of the intensification of modern agriculture and landscape horticulture systems is that, besides the increasing pollution and other environment problems, many aspects of the production systems and practices are less amenable to recycling by-products and waste from production processes (Polprasert, 2007). Reduction in use of synthetic chemicals also has the potential to conserve energy use in the bioproduct processing, and distribution and marketing chain (Conacher and Conacher, 1998; Yiridoe et al. 2009). Thus, there is a need for organic alternatives to peat-based bioproducts.

The search for alternatives to chemical fertilizer and peat use has been the subject of considerable R&D efforts. Various forms of compost from agricultural and forestry wastes have been tested as peat substitutes in the horticulture sector (Bustamante et al., 2008). Other studies have evaluated the technical feasibility of biological alternatives to peat, such as composted bark, manure and urban waste (Nappi and Barberis, 1993; and Inbar et al., 1986). Product consistency and user-friendliness are important technical challenges to bioproduct acceptance and use (Allen and Kovach, 2000). The environmental impacts and benefits associated with diverting biomass from landfills for use in producing bioproducts as alternatives to peat is an important applied research and knowledge gap (Rajaram et al., 2011).

In this study, a life cycle analysis (LCA) framework proposed by the International Organization for Standardization, ISO (ISO, 2006) was used to evaluate the environmental impacts associated with processing, producing and marketing three novel bioproducts. The analysis focused on three novel bioproducts developed by a bioproducts processing company in New Brunswick, Canada, including: i) a dehydrated composted forestry bark (DCFB), intended to be used as an intermediate bioproduct (along with peat) in producing horticulture amendments; ii) dehydrated topdressing (DTD) bioproduct; and iii) organic bio-fertilizer (OBF).

Research Methods

Environmental and ecological impacts were investigated using indicators commonly used in the scholarly literature to capture: i) global warming; and ii) human and eco-toxicity impacts. Indicators for global warming impacts, including CO_2, CH_4 and N_2O were transformed to CO_2-equivalents, consistent with procedures proposed by the United Nations Intergovernmental Panel on Climate Change (Government of Australia, 2001). Indicators for human and eco-toxicity impacts included SO_2, NO_X and CO. In addition, major inputs used for the bioproducts processing were quantified, including sawdust levels burned to generate heat energy, diesel fuel consumption association with biomass feedstock acquisition/delivery to the processing plant, inherent energy associated with the diesel fuel use, and electricity consumption in the processing and packaging of the three bio-products.

Data and Assumptions*:* Data and other information used in the analysis were obtained from various sources, including: i) various unpublished bioproducts company documents and databases; ii) interviews with technical staff of the bioproducts company located in New Brunswick, Canada; iii) economic engineering recommended practices and standards of the American Society of Agricultural and Biological Engineers; and iv) technical parameters and statistical data from government agencies such as Environment Canada, Natural Resources Canada, and Statistics Canada.

LCA: Impact Assessment and Assumptions: To determine the environmental impacts per tonne of each bio-product produced, it was assumed that the processing plant produced 20 tonnes of DCFB, 10 tonnes of DTD, and 3 tonnes of OBF per hour. Total annual plant operation was 3,000 hours, based on actual hours for the bio-products company. Major inputs used were grouped into: (i) biomass feedstock and other raw inputs (i.e. feedstock, sawdust, bags); (ii) energy (from fuel and electricity) consumption; (iii) labor; (iv) land; and (v) machinery and equipment (Table 1). Outputs included the three bioproducts. In addition, by-products generated included: i) GHG emissions linked to transportation, composting, and heat and electricity use; ii) atmospheric emissions from electricity use (i.e., SO_2); iii) nutrient leached from stockpiled biomass feedstock, composting and application of end-products; iv) residue from burning sawdust (i.e. smoke and ash); (v) heat; (vi) steam; and (vii) motor vehicle exhaust emissions. Quantifying environmental impacts required first identifying the impact categories and specific indicators linked to particular impacts. In this study, data availability limited the impact analysis to three main impact categories: (i) global warming; (ii) energy depletion; and (iii) resource depletion.

Results and Discussion

Important characteristics and constituents of the three bioproducts are summarized in Table 2. Feedstock and other inputs used, and the processes for producing all three bio-products meet current Canadian organic standards. For example, there were no additives or colorants, consistent with the requirements for organic certification.

Input use Comparison

Diesel fuel consumption reflected transportation distance to source of raw biomass feedstock, and was highest for poultry manure (3.68 L tonne^{-1}), and lowest for forestry bark

Table 1: Biomass and Feedstock Inventory

Feedstock and other inputs				**Initial processing**	
Item	**Raw inputs**	**Source**	**Typical Transportation Distance**	**Technique**	**Time required/ storage**
Composted forestry bark	Forestry bark	Local forest mills Pulp and paper mills Sawmill Woodlot operators	10 km	Composting	2 years
Processed manure-based organic bio-fertilizer	Poultry manure	Local framers	250 km	Mixing and conditioning	1 week
	Potato residue	Local famers Potato processing plants Potato chip plant	200 km	Mixing and conditioning	1 week
Calcium lignin-sulphonate organic binder	calcium lignin-sulphonate organic binder	Local lignin supply company	5 km	n.a.	n.a.

Source: Envirem Organics Inc. (unpublished documents), and personal communication with Envirem Organics Inc. staff.

Table 2: Characteristics of Novel Bioproducts

Bioproduct type	**Blend Constituents**	**Texture/size**
Dehydrated composted forestry bark (DFCB)[1]	- 100% composted forestry bark (i.e. coarse portion dried-screened black earth compost)	Coarse: (1/4 - 5/8 inch)
Dehydrated topdressing (DTD)	- 70% composted forestry bark (fine portion dried-screened black earth compost) - 30% processed manure-based organic bio-fertilizer (15% poultry manure, and 15% potato residue feedstock)	Fine: (<1/8 inch)
Organic bio-fertilizer (OBF)	- 95% processed manure-based organic bio-fertilizer (i.e., 47.5% poultry manure, and 47.5% potato residue feedstock) - 5% calcium lignin-sulphonate organic binder	Medium: (1/8 - 1/4 inch)

Source: Enviren Organics Inc. (unpublished data)

(0.147 L $tonne^{-1}$). For a given raw biomass input, diesel consumption per tonne of dehydrated bio-product produced varied depending on the proportion of the raw input used in producing the bio-product. The estimates suggest that more diesel fuel was consumed in producing a tonne of dehydrated DCFB (0.09 L) than for DTD (0.063 L).

Sawdust consumption was highest for producing a tonne of dehydrated DCFB (0.0614 tonnes), and lowest for a tonne of dehydrated OBF (0.0218), partly because the proportion of forestry bark in DCFB (i.e., 100%) was higher than its proportion in DTD (70%) and OBF (0%). Total electricity consumption per tonne for each of the three bioproducts was highest for OBF (40kWh), followed by DTD (12kWh) and then DCFB (6 kWh) (Table 3). Electricity use per hour was assumed to be the same for each of the three bioproducts. Yet, production per hour was highest for DCFB (20 tonnes) followed by DTD (10 tonnes), and lowest for OBF (3 tonnes per hour). The high volume of DCFB produced per hour resulted in lower average consumption of electricity for per tonne of DCFB produced.

Energy Consumption: Energy consumption estimates reflected inherent energy in diesel fuel used: i) to transport biomass from the various locations to the processing facility; and ii) to fuel excavator for turning of compost biomass feedstock. Inherent energy in diesel fuel consumption was a function of the distance to biomass sources. In addition, inherent energy in electricity used in the processing plant was estimated (Table 3). The total amounts of inherent energy associated with the three bioproducts processed are summarized in Table 4. Total energy consumption required to produce a tonne of final bioproduct was highest OBF (285 MJ), and lowest for DCFB (34 MJ). The relative amount of total energy consumed at the processing plant versus the biomass acquisition/transportation depended on the final bioproduct type. For example, for OBF and DCFB, a higher proportion of energy was consumed within the processing plant than energy amounts associated with constituent biomass transportation.

Environmental Impacts

Environmental impacts were investigated using the global warming and climate change indicators, and human and eco-toxicity indicators discussed earlier.

Global Warming Impacts: All GHG emission impacts were aggregated on a CO_2-equivalent basis, separately for biomass acquisition and transportation, and for processing the three bioproducts within the plant (Tables 3 and 4). Total CO_2-equivalent for producing a tonne of dehydrated bioproduct was highest for OBF (28,934 g) and lowest for DCFB (3,654 g). The high GHG emission impacts for OBF relative to the other two bioproducts was due not only to a higher proportion of poultry manure and potato residue in OBF (0.475), compared with the fraction of the two raw biomass feedstock in DTD (i.e., 0.15), but also because of high energy consumption-related GHG emissions associated with potato sludge/residue (Table 4). The global warming potential avoided by diverting waste from landfills to the bioproducts processing plant was highest for biomass used in the production of a tonne of dehydrated DTD (approximately 2 tonnes), and lowest for OBF production (1.2 tonnes).

Human and Eco-toxicity Impacts: indicators for these impacts included CO, SO_2 and NO_X emissions. In general, NO_X emissions were highest, followed by SO_2, and then CO, across all three bioproducts produced. In addition, the human and eco-toxicity gaseous emissions were highest for producing OBF, and lowest for DCFB production (Table 4).

Table 3: Electricity consumption, emissions and energy use per tonne of dehydrated bioproduct production processes

	Dried composted forestry bark	**Dehydrated topdressing**	**Organic bio-fertilizer**
Electricity consumption (kWh)	6	12	40
CO_2 (g)	2,730.00	5,460.00	18,200.00
CH_4 (g)	0.07	0.14	0.48
N_2O (g)	0.06	0.12	0.40
Total CO_2 eq. (g)	2,749.68	5,499.36	18,331.20
SO_2 (g)	13.74	27.48	91.60
NO_x (g)	10.38	20.76	69.20
Energy (MJ)	21.60	43.20	144.00

Table 4: Total emissions and energy use per tonne of dehydrated bioproducts produced

	Dried composted forestry bark	**Dehydrated topdressing**	**Organic bio-fertilizer**
a) Biomass feedstock acquisition			
Total CO_2 eq. (g)	662.096 (18%)[1]	3808.637 (40%)	10,602.950 (37%)
SO_2 (g)	1.156	6.652	18.519
NO_x (g)	17.617	101.340	282.121
CO (g)	3.789	21.797	60.680
Energy (MJ)	8.808	50.670	141.061
b) Processing			
Total CO_2 eq. (g)	2,992.348 (82%)	5,669.228 (60%)	18,331.200 (63%)
SO_2 (g)	14.164	27.777	91.600
NO_x (g)	16.937	25.362	69.236
CO (g)	1.664	1.195	0.0974
Energy (MJ)	24.828	45.460	144.00
c) Total			
CO_2 eq. (g)	3,654.444	9,477.865	28,934.149
SO_2 (g)	15.320	34.429	110.119
NO_x (g)	34.554	126.701	351.357
CO (g)	5.453	22.992	60.777
Energy (MJ)	33.637	96.130	285.061

[1] Figures in parentheses indicate percent of total in part (c).

Summary and Conclusions

The empirical results from this study support findings that landfilling is generally less beneficial (both in terms of economic and environmental considerations), especially with no energy recovery, compared with windrow composting. The environmental benefits from producing the three value-added bioproducts takes on an increased dimension when considered in light of the diminishing peat reserves in Atlantic Canada, and the negative ecological consequences associated with harvesting peat moss. The benefits associated with diverting biomass from landfills for use in producing the bio-products at the processing plant extends beyond landfill gas emissions reduction.

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