Carbon and Global Warming Potential Footprint of Organic Farming

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Executive Summary

This study was undertaken to determine if sufficient evidence exists to substantiate organic branding and image development based on environmental benefits of organic farm management. The focus of the analysis was all greenhouse gases (CO_2, CH_4 and N_20) and farm energy use converted to a net CO_2 equivalent (GWP) footprint. A second objective was to research which areas of existing carbon footprint research are inadequate and would benefit from additional investigation under the "Environmental Stewardship and Product Branding" project of the Organic Science Cluster proposal, coordinated by the Organic Agriculture Centre of Canada and involving researchers from all across Canada.

The study involved an extensive review of the literature comparing energy use (E) and GWP of organic and conventional production systems (~ 120 studies analysed). In addition to reviewing meta-comparisons, we carried out a sectoral analysis involving field crops, beef, dairy, hogs, poultry, vegetables, fruit, and greenhouse production. We started each sectoral analysis with a review of Canadian literature, followed by US and finally EU and other international data. Cross cutting issues such as tillage, compost, soil carbon sequestration and energy offsets were also reviewed. Finally, we put this comparative data in context by quickly reviewing literature on E and GWP data from the food system, primarily using US data in the absence of Canadian analyses.

We encountered a number of challenges that included gaps in data, especially for some sectors; differences in the scope of studies (some analyzed E alone or GWP, some were field or whole farm studies, input/output analyses, life cycle assessments [LCA] or emergy studies); inconsistent methodology (some used older IPCC coefficients, some included soil C credits, some examined non-renewable energy use only vs. all energy including human labour); and differences in units of measurement reported (per ha, per product).

To determine whether branding would be possible, we set out a number of conditions that would have to be met:

1. Clear and consistent differences – 20% as a minimum threshold difference between organic and conventional production
2. Consistent approach to reporting/units
3. Consistent approach re: N_2O emissions
4. Acceptable methodology
5. That differences are consistently realizable
6. That differences are meaningful relative to other strategies for reductions within the food system
7. That some verification is feasible

We concluded that creating a brand for organic farming related to energy use and energy efficiency, both on a per hectare and per farm product basis, is possible. In all sectors but poultry and fruit, our 20% threshold of differences was surpassed in the majority of studies. Data for poultry production is particularly limited, and most of it favours conventional production based on significant yield differences in the 2 systems. For fruit production, more research has been carried out than poultry (though still limited relative to other sectors) and the most common conclusion of the comparisons was that differences between the systems are minimal.

Branding organic farming related to GWP, both on a per hectare and per farm product basis, is possible only for a few sectors, with results per ha more consistently favouring organic farming than GWP per unit product. With further research in North America, where the gaps between organic and conventional yields are less extreme than in Europe, branding on the basis of GWP might be feasible in the medium term.

Regarding cross cutting issues, we found that the use of more conventional tillage, compared to minimum till, was consistently a negligible contributor to farm E use (often only ~5% of total) and that any additional tillage on organic farms does not significantly deplete soil C compared to no-till or minimum till systems. In fact, studies often showed the inverse to be true, that green manures and forages increased soil C on organic farms regardless of added tillage. Regarding energy offsets, energy crops and residues have a much more limited role on organic farms compared to conventional ones, because of the need to use organic material for nutrient and soil building purposes, and the high demand for organic production targeted to human markets. Similarly, biogas production will likely play a more limited role, given the limited amount of manure that can typically be directed towards on-farm biogas, and the degree to which anaerobic digestion is discouraged in organic standards.

Assuming that farm E use represents a gross average of 35% of total food chain E use (Canning et al. 2010) and continues to increase, an improvement of 20% or more in E efficiency through organic farm management would represent a reduction in food-chain E use of 7% or more. In practice, farm E use as proportion of total food chain E use varies widely by sector, thus, benefits of organic farm management may be even greater in some areas. Among food supply chain stages other than agriculture, the wholesale/retail stage (including cooling and packaging) and the processing stage represent similarly large contributors to the entire food supply chain, often contributing 30% or more to total food system E costs. Thus, additional improvements in food system E use can be obtained by emphasizing reduced processing, whole foods and food waste minimization. Organic processing protocols, through their emphasis on minimal additives, limited numbers of ingredients, and less degrading process techniques, may already offer efficiencies, an aspect that requires more study. Finally, reducing transport offers some additional, if smaller, potential for E and GHG gains and a significant body of literature has examined relative E and GHG efficiency of various freight modes. Ultimately, it will be important for the organic sector to note that the improvements in efficiency gained at the farm level, can be lost through inefficiencies further along the supply chain, including the processing, transporting and wholesale / retail functions.

Future research needs include:

- Organic processing efficiency strategies
- Transportation – need basic understanding of food supply chains, plus efficiencies and coefficients
- Canadian data for horticulture, poultry, hogs, dairy and beef
- GHG direct measurements in different agroecosystems
- E use in the Canadian food system

Introduction

Purpose of the study

At its January 2009 meeting in Guelph, in the context of discussions regarding the organic brand architecture and promotional strategies, the Organic Value Chain Roundtable (OVCRT) agreed that the Market Development Working Group (MDWG) would examine the possibility of a Greenhouse Gas Study for the Organic Sector which might be used to develop defensible proof points to support product differentiation claims. The object of the study is to determine if sufficient evidence exists to substantiate organic branding and image development based on environmental benefits of organic farm management. This phase would take into account all greenhouse gases (CO_2, CH_4 and N_2O) and farm energy use which would be converted to a net CO_2 equivalent carbon footprint.

OACC will also research areas of existing carbon footprint research that are inadequate and would benefit from additional investigation under the "Environmental Stewardship and Product Branding" project of the Organic Science Cluster proposal.

Method

In constructing this analysis, we have reviewed studies on organic agriculture and adapted pertinent interpretations from conventional agricultural research on energy efficiency. We extensively searched the academic literature and key summary reports from the NGO and governmental sectors in Europe and North America. We did not include studies of crops that can not be grown in Canada. We attempted to categorize the studies by region and analytical method. Where studies attempted meta-level assessments, we attempted to avoid double counting studies.

General overview of the issues

The organic philosophy and standards (Canadian General Standards Board, 2006) impose a specific set of realities on farms that affects their energy efficiency and GHG emissions; realities that differ from those on most conventional farms. Contrasts of organic and conventional operations, however, pose analytical difficulties, given that finding comparable operations is often challenging, especially in livestock systems. Organic operations, while still adhering to standard requirements, can be tremendously variable in management approaches. However, in comparison with conventional operations, organic farms typically have more diverse crop rotations, lower livestock stocking densities and different land base requirements, all of which affect energy consumption. Consequently, farming system level comparisons are usually more pertinent than comparison of specific operations within these systems, although most studies conducted to date are based on comparisons of specific crops.

From a systems perspective, organic farming usually leads to reductions in energy use and GHG emissions and also provides opportunities to integrate the four pillars of global warming strategy, i.e. emissions reduction, carbon sequestration, biomass offsets and adaptation. Relative to most conventional farm operations, organic farming reduces soil erosion, stores more C, does not require synthetic N and pesticides (and their associated emissions), eliminates N_2O emissions from non-biological sources, discourages anaerobic digestion of manure (and the associated methane emissions)[1], often has lower animal stocking densities which generally contribute to lower methane emissions , consumes less energy and water overall, and has higher percentages of the farm landbase in perennial crops (including pasture) and shelterbelts (MacRae et al., 2004; Lynch, 2009).

Energy is used throughout the food supply chain, including growing of crops and livestock production, manufacture and application of agricultural inputs, processing, packaging, distribution and cold storage, preparing and serving, and disposing of waste. Recent studies of the US food system (Canning et al., 2010, Weber and Matthews, 2008) have shown that most (50-70%) of the average households' carbon footprint for food consumption comes from farm production and subsequent processing, with transport accounting for only an average of 11%, respectively, across all sectors or food products. Similar results, in which transport accounted for 9% of the food chain's greenhouse-gas emissions have been obtained recently in a British national study entitled Food 2030 (HM Government(UK).pdf. However, in the USDA report by Canning et al. (2010), energy costs of production vary widely between sectors. In addition, as household and food service food preparation activities continue to diminish and are outsourced to food processors, energy use at the food processing and farm level in the US is projected to increase a further 27% and 7% respectively, even when energy embodied in purchased inputs is excluded from the calculations. These studies suggest a focus on farm level E use as impacted by farm management system is very appropriate.

This study is also timely because tentative steps have already begun towards GHG branding.. In Europe, EOSTA B.V. Holland, a leading importer and distributors of fresh organic fruits and vegetables, has attempted to integrate GHG measures into its standards for producers through its Nature and More labelling and tracking scheme that allows consumers to collect information on GHG emissions associated with the product. A current claim is for a carbon neutral orange[2], tomato[3] and other fruits and vegetables. Certification of GHG emission reductions is carried out by TÜV[4], an organization accredited by a UN agency to carry out functions such as these. A Swedish initiative, Climate Labelling for Food (2009), sponsored by the organic certifier KRAV, Swedish Seal, and several major food companies has developed preliminary standards and audit systems that cover a range of farming systems[5] (see also Sonnesson et al. 2009a-e). The purpose is 'decreasing climate impact by creating a labelling system for food through which consumers can make conscious climate choices and businesses can increase their competitive power'. Qualifying operations would receive the label "Climate-certified production". Both approaches suggest that organic product by product branding is feasible, but the question remains whether organic sector wide branding is feasible. That is the focus of this report.

Organization of the report

We first review what needs to be in place to warrant a farm-level sector wide branding approach, then, provide a brief overview of some of the larger meta-analyses that have attempted to draw sector wide conclusions. We follow that with a discussion of the state of the data in the main commodities, and not all have been equally treated in the literature. Issues that cut across commodity areas, particularly tillage, composting and carbon storage are then addressed. Finally we examine the farm level data in relation to some of the larger food system themes in order to place this issue in context.

What needs to be in place to warrant farm – level carbon branding?

Environmental branding is typically about differentiation. Although the specific nature of a branding approach for organic agriculture has yet to be determined, presumably a key message is that consuming organic is consuming smarter; consuming for environmental benefit. In his executive summary on the Canadian Organic Brand, Matt Holmes argues that "The brand equities for the Canadian organic sector have been defined as: Integrity, Sustainable, Healthy, Canadian, Passionate and these five elements are invested in our brand pillars of **Caring**, **Credible**, and **Committed,** upon which the Canadian organic sector is founded."[6] The sector must clearly communicate "adherence to rigorous standards, the quantifiable and anecdotal benefits of organic agriculture, the transparency and traceability in addition to consistently delivering the brand promise."[7] One strength of such an approach is that it commits the sector to its own value base and to negating any potential for organic to be viewed as a greenwashing initiative.

This study focuses on the state of evidence in support of farm-level benefits of organic production in Canada[8]. If the above summary is widely ascribed to by the sector, then we believe the state of evidence would need to be characterized in the following ways to warrant such branding.

1. Clear and significant differences exist in energy and GHG emission performance between organic and conventional operations. No commonly accepted threshold of system differences currently exists, but given variability in farming systems, our presumption is that average improvements of at least 20% by type of measurement would be required across all production areas to warrant claims of differences between organic and conventional systems. Below such a level, it would be legitimate for critics to argue that system variability could just be artifactual relationships.
2. There is a consistent approach to how emissions are reported. i.e. whether on a per land unit basis or product basis. The latter, the 'intensity of emissions' (i.e. per unit product) is also useful in pointing towards indirect methods of mitigation (i,e. by increasing yields etc.). Bertilsson et al. (2008) argue that while E use per unit yield expresses system E efficiency (and is often lower in organic systems), the measure is insufficient to compare E characteristics of farming systems, especially when yields are being reported on single crops rather than the productivity of the whole rotation. Net E production per unit land area is recommended as a more equitable measure. A counter argument to this approach is that while organic farming does generally require more land to produce the same total yield, it conserves soil, water and above and belowground biodiversity, and even maintains and restores multifunctional landscapes (Gomiero et al., 2008; Lynch, 2009; Scialabba and Muller-Lindenlauf, 2010) and these key environmental benefits cannot be overlooked. Additionally, conventional production is associated with the degradation of hundreds of millions of hectares of land worldwide according to FAO , and much farmland globally is misallocated to non-food crops, suggesting that land availability is not as great a constraint as offered by organic critics.
3. A consistent approach to whether a credit for soil carbon (C) sequestration is included in the estimates. Soil C sequestration is discussed below.

4. A consistent approach with respect to N_2O emissions from biologically fixed N by legumes is essential in whole farm and cropping system estimates of GHG emissions (Lynch 2009). Nitrous oxide (N_2O) emissions from soil are related to (i) the N cycle in the soil and losses from the processes of nitrification and denitrification and (ii) losses from the N contained in crop residues which ultimately decomposes releasing N though the N cycle processes. Until recently, however, N_2O was assumed to be emitted also directly from standing legume crops fixing N_2 biologically from the atmosphere. Organic farming systems are highly dependent on legume N_2 from biological nitrogen fixation (Roberts et al. 2008; Lynch et al. 2008). As N_2O emissions appear not to be directly derived from legume N_2 fixation as previously assumed by the Intergovernmental Panel on Climate Change (IPCC 1997), Rochette and Janzen (2005) and Janzen et al. (2006) have argued for a revised IPCC coefficient related to legume N_2 fixation, since this concept has been implemented and acknowledged, particularly in more recent studies.
5. Accepted measures for determining differences. Gomiero et al. (2008) highlight the main challenges of organic vs. conventional studies:
   - the degree to which a holistic analysis is employed over the long term, looking at integrated farming systems[9], and the related problem of comparability across systems that can differ significantly in crop mix and stocking rates
   - variability in energy accounting measures; many studies do not take a farm to fork or Life Cycle Analysis (LCA) approach[10]
   - the extent to which the study addresses whether externalized costs are internalized

   Ideally, the conditions for a meta-analysis[11] of studies would exist; however, according to Mondalaers et al (2009), they do not exist for organic / conventional comparisons, so there is a current requirement for less robust approaches. At a minimum, there must be relative agreement on the elements and measurement of comparison to assure some consensus on the data and its meaning. In many cases, the measurement of baseline emissions from conventional operations is also variable which complicates the organic / conventional comparison (cf. Sonneson et al. 2009a related to hog production). Such differences can be produced for reasons of methodology or operation differences. Other sectors have such elements:For example, the World Resources Institute series of methods and tools (www.ghgprotocol.org). At this point, no specific standard methodology is used for organic/conventional comparisons, though many may follow the related WRI standard on land use change, http://www.ghgprotocol.org/files/lulucf-final.pdf. Also being used are the guidelines of the IPCC (2007) and the eco-balance guidelines (ISO 14040 and 14044).
6. Generally, agreement that these differences are consistently realizable; in other words that they are not so variable by time and space that no consistent patterns emerge.
7. The changes represent a permanent improvement. The presumption of such comparisons is that the gap between organic and conventional in regard to these measures remains constant.
8. The differences actually mean something in the context of food system GHG mitigation and energy efficiency. For example, does it make more sense to have more farmers convert to organic, or have 50% of conventional operations dramatically reduce N fertilizer use? Convert to organic or dramatically reduce livestock densities and consumption? Or does supporting well managed organic farms, by demonstrating the

practical and economic viability of both these production options, i.e. reduced livestock density and alternatives to N fertilizer use, broadly contribute to overall GHG mitigation and energy efficiency?

9. That some verification measures either at the sectoral or farm level are feasible, depending on the nature of the branding. It is not the purpose of this study to examine verification systems per se, but rather to identify if the current state of the data makes verification possible.

In comparison with conventional operations, organic farms typically have more diverse crop rotations, lower stocking rates and different land base requirements, all of which affect energy consumption. Consequently, farming system level comparisons are usually more pertinent than comparison of specific operations within these systems, although most studies conducted to date are based on comparisons of specific crops. Models are powerful tools to track flows of carbon, nitrogen, and energy in complex systems such as whole farms and to determine the net effect on greenhouse gas emissions (Janzen et al., 2006). Most farm practices (including cropping system, fertilizer rates, livestock numbers, animal diet, feeding practices, tillage practices, irrigation, manure storage) can have multiple interactive effects on emissions throughout a farm including release of N_2O and CH_4, and storage of C in soils. Janzen et al. (2006) described a model approach for identifying practices that best reduce net, whole-farm emissions on Canadian farms. But, in contrast to the European Union (Dalgaard et al., 2001; Olesen et al. 2006; Bos et al., 2007, Halberg et al. 2008; Kustermann et al. 2008), no North American studies to date have attempted to model and gauge comparative GHG emissions on a whole-farm basis as affected by organic management. Such studies are extremely useful at integrating all aspects of farm management including, in some cases, energy use. In Denmark, for example, Dalgaard et al., (2001) found energy use to be lower in organic agriculture both per hectare and per unit crop or livestock product (Dalgaard et al. 2001).

More recently a new ‘Holos’ whole farm modelling software program has been developed by Agriculture and Agri-Food Canada (AAFC) to estimate net GHG emissions for individual farms and identify practices, in various sectors, that might mitigate emissions. Algorithms are generally based on IPCC methods but have been adapted for Canadian conditions, with the level of detail determined by amount of available scientific information (Little et al., 2008). The broad limitations of the current version of Holos (version 1.1x) for work on specific organic production sectors are discussed under sectoral analyses. As noted under dairy below, Holos is being applied to commercial organic dairy farms within a new project under the Organic Science Cluster research program. Categories of emissions in the current version of Holos include; (i) Soil N_2O – direct (ii) soil C (iii) enteric CH_4 (iv) manure N_2O – direct (v) soil and manure N_2O – indirect (vi) manure CH4 (vii) lineal tree planting C and (viii) energy use CO_2.

Sectoral Analysis

In the following sectoral analysis section we order studies as Canadian, then US, then European.

In their recent meta-analysis of a wide range of global organic vs. conventional comparisons, Gomiero et al.(2008) found …

> "lower energy consumption for organic farming both for unit of land (GJ/ha), from 10% up to 70%, and per yield (GJ/t), from 15% to 45%. The main reasons for higher efficiency in the case of organic farming are: (1) lack of input of synthetic N-fertilizers (which require a high energy consumption for production and transport and can account for more than 50% of the total energy input), (2) low input of other mineral fertilizers (e.g., P, K), lower use of highly energy-consumptive foodstuffs (concentrates), and (3) the ban on synthetic pesticides and herbicides".

All the commodity-based studies showed lower energy consumption in organic production per unit of land, but a few showed higher energy consumption per yield in the organic systems, particularly for potatoes and apples. For these crops, knowledge of organic production has not been as well developed as field crops and dairying, and consequently many operations were reporting significantly lower yields than in conventional production, a disparity that has been reduced over time. In these cases, even though gross energy use was lower, measured against yield, the comparison was less favorable to organic production.

Similar to their review of energy efficiency studies, Gomiero et al. (2008) consistently found that organic systems had significantly lower CO_2 emissions than comparable conventional systems, when measured on a per area basis, though in some systems that benefit was lost when measured per tonne of production, depending on yield differences. Most of their review focused on European studies where the intensity of conventional production produces greater spreads in yields than those found in North American studies (MacRae et al., 2007). No Canadian work was included in their analysis.

Mondalaers et al. (2009) in their meta analysis involving some studies not covered in Gomiero et al. (2008) also concluded that emissions were significantly lower under organic production on a per area basis and the same on a per unit of production basis. The per area improvements were based on lower concentrate feeding, lower stocking rates and the absence of synthetic nitrogen fertilizer.

Kustermann and Hulsbergen (2009), in a review of 33 German organic and conventional commercial farms and examining direct and indirect energy inputs, GHG fluxes and C sequestration, found that energy use per ha in the organic operations was dramatically lower than conventional (2.75 time lower / area), but that, although the mean was significantly lower (72% of conventional), the higher variability in GHG emissions / ha on organic farms meant that the upper range of emissions on the organic operations was comparable to conventional ones, though the lower range was significantly lower (28 GH/ha for the organic operation vs. 51 for the conventional operation). Nitrous oxide and carbon dioxide emissions were clearly lower in organic farms, with much higher C sequestration.

Consequently, given the current state of the literature, for each sector, we look at the state of the data for energy use and the three main GHGs (carbon, methane, nitrous oxide) and also examine intensive vs. extensive production studies, with an eye to interpreting European results for the NA context.

Field crops

Snyder and Spaner (2010) recently conducted a review of the sustainability of organic grain production on the Canadian Prairies, including many of the Canadian studies discussed in detail below. Notably, the authors conclude that management quality in either organic or conventional systems is key and well managed conventional systems may outperform organic systems, i.e. that adoption of some organic technologies in conventional field crop production systems would likely ameliorate the general higher C cost of these systems .

Nelson et al. (2010) in their recent survey of 250 prairie region conventional and organic grain growers, provided added evidence regarding the differences in agronomic practices between these management systems, particularly with respect to use of tilled summerfallow, compost and green manures. The implications with respect to the net effect of the added tillage (including summerfallow) but often added C inputs (from crop residue and amendments) on soil C sequestration on organic grain farms are discussed below in the section on tillage.

A 12-yr study in Manitoba of two forage and grain crop rotations and two crop production systems (organic versus conventional management) on energy use, energy output and energy use efficiency, found energy use was 50% lower under organic compared with conventional management (Hoeppner et al. 2006). Energy efficiency (output energy/input energy) was highest in the organic and integrated (i.e. forage included) rotations. Tillage differed between crop production systems primarily with respect to alfalfa termination; by herbicide application in the conventional system versus two to three cultivations with sweep cultivators in the organic system. Herbicides were also used to control weeds in the conventional system, while occasional light harrowing was required to control weeds in the organic system. In addition to crop yield, data collected included all crop inputs (seed, fertilizers, pesticides) and fuel and machinery needed for all field operations. This information was then converted into energy values (MJ ha-1). The absence of inorganic N fertilizer was the main contributor to reduced energy inputs and greater efficiency. It could be argued that the relatively reduced degree of mechanical weed control required in the study by Hoeppner et al.(2006) is somewhat atypical of many current commercial organic crop production systems. ‘State of the industry’ type information, such as that provided by the recent study of Nelson et al. (2010), that provides some insights and data on organic grain farm tillage use, could be used as a basis to assess the relative impact of tillage practices on farm net GHG emissions. This could be assessed initially using virtual ‘model’ farm systems and Holos or another suitable model. However, as noted in the following study by Khakbazan et al. (2009), anddiscussed below in the section on tillage, and also found by Zentner et al (2004), tillage intensity and type typically have a minor overall effect on total farm E use.

Khakbazan et al. (2009) reported from Manitoba on a comparison of 16 alternative management practices for a wheat-field pea rotation on economic returns, non-renewable energy use efficiency, and GHG emissions. While a strictly organic management system was not included, the study is informative as ‘low-input’ treatments for wheat with respect to N fertilizer (20, 40, 60 and 80 kg N ha^{-1}) and herbicide (reduced vs. recommended rate), along with high disturbance

(HDS) vs. low soil disturbance (LDS) seeding options for both crops, were included. Over a four-year period (two rotation cycles), the 16 management systems were evaluated using data from field experiments conducted on two soils (clay loam and loam textures). Using coefficients mostly derived from Nagy (2000), direct CO_2 emissions were estimated from inputs (including diesel fuel, lubricants and electricity) and also CO_2 emissions embedded in all aspects of fertilizer manufacture including inputs, production and transportation. Indirect CO_2 emissions were estimated for machinery and pesticides. Methane (CH_4) losses were primarily from fuel. Nitrous oxide (N_2O) emissions, as for any cropping system, are related to (i) the N cycle in the soil and (N_2O) losses from the processes of nitrification and denitrification (ii) losses from the N contained in crop residues which ultimately decomposes releasing N though the N cycle processes as in (i). Notably, it was assumed there were no N_2O emissions from legumes. Energy output was calculated as gross E content of the harvested grain less seed requirements. Energy use efficiencies (or intensities) (E output minus input, or expressed as a ratio of output to input or quantity of grain produced per unit of E input) were expressed on a per hectare basis for the complete rotations and for individual crops within rotations. Fertilizer E use, primarily N, accounted for the largest E input at 52% of total use, followed by fuel and lubricants at 34%, herbicides at 8% and manufacture and repair of machinery at 6%. Overall, increased GHG emissions associated with an increase in N fertilizer were not offset by an increase in yield (and C retained) and an increase in N fertilizer from 20 to 80 kg N ha^{-1} increased whole farm energy requirements by 40%. It was notable that soil available N levels were moderate to high, however, thus reducing the response to fertilizer N. However, this condition could be expected following incorporation of green manure prior to wheat as commonly practiced in organic systems. Thus, E use efficiency was highest for the lowest rate of fertilizer N application for both tillage systems with grain output efficiency (Kg per GJ of energy input) decreasing from an average of ~800 to ~650 and E output/input ratio decreasing from approximately 13 to 7 on average as N fertilizer input rose. The LDS tillage system did increase the amount of soil C sequestered compared to HDS system, but method of tillage had a negligible overall effect on total farm E use. It was notable that total crop emissions were much lower for the legume (pea crop) than wheat, as less N fertilizer was applied.

An LCA modeling analysis of a Canada-wide conversion to organic canola, wheat, soybean and corn production concluded that under an organic regime, these crops would consume “39% as much energy and generate 77% of the global warming emissions, 17% of the ozone-depleting emissions, and 96% of the acidifying emissions [sulfur dioxide] associated with current national production of these crops. Differences were greatest for canola and least for soy, which have the highest and lowest nitrogen requirements, respectively.” (Pelletier et al., 2008). In general, the substitution of biological N for synthetic nitrogen fertilizer and associated net reductions in field emissions were the most significant contributors to better organic production performance. The authors concluded that organic yields had to be unrealistically below conventional before GHG emission reductions were eliminated, although their assumptions of organic field crop yields of 90-95% of conventional (as found in many USA studies) may not be realistic in all Canadian landscapes (MacRae et al., 2007).

Zentner et al. (2009), using data collected over the 1996-2007 period from a long term cropping systems trial at Scott, Saskatchewan, , examined (i) non-renewable energy inputs and energy use efficiency, and (ii) economic merits of 9 cropping systems, consisting of 3 input management methods and 3 levels of cropping diversity. Input treatments consisted of (i) high input (HI) -

conventional tillage with recommended rates of fertilizers and pesticides as required; (ii) reduced input (RI) - conservation tillage and integrated weed and nutrient management practices; and (iii) an organic input (OI) system - tillage, non-chemical pest control, and legume crops to replenish soil nutrients. The crop diversity treatments included (i) a fallow-based rotation with low crop diversity (DLW); (ii) a diversified rotation using cereal, oilseed and pulse grains (DAG); and (iii) a diversified rotation using annual grains and perennial forages (DAP). All crop rotations were 6 years in length. Total energy input was highest for the HI and RI treatments at 3855 MJ ha^{-1} and 51% less for the OI management system. Most of the energy savings under OI management came from the avoidance of use of inorganic fertilizers and pesticides. In addition total energy use was highest for the DAG treatments at 3609 MJ ha^{-1}, and similar but about 17% lower for the DAP and DLW treatments. Thus, the highest energy requirements (4465 MJ ha-1) were associated with HI/DAG and RI/DAG treatments and OI/DAP had the lowest (1806 MJ ha-1). Energy output was typically highest for the HI input systems at 26543 MJ ha^{-1} (and ~ 4% less with RI), and 37% less with OI management, due to lower crop yields. Energy use efficiency, measured as yield of grain plus forage produced per unit of energy input or as energy output/energy input ratio, was highest for the OI managed systems (501 kg of harvested production GJ^{-1} of energy input, and an energy output/energy input ratio of 8.85), and lower but similar for the HI and RI systems (377 kg per GJ^{-1} and 6.79 ratio). The authors conclude that organic management and a diversified rotation using perennial forages (DAP) was the most energy efficient cropping system, while RI/DLW and RI/DAG generally ranked lowest.

In most organic field crop systems, total N inputs to soil, and the potential for N_2O emissions, are reduced compared to conventional systems. However, an increased risk for N_2O emissions occurs in organic farms occurs following the flush of soil N mineralization after incorporation of legume green manure or crop residues. As noted by Scialabba and Müller-Lindenlauf (2010), however, when measured over the entire crop rotation, N_2O emissions are generally lower for organic field crop systems. The authors cite one German study in which emissions, while peaking at 9 kg N_2O ha^{-1} following legume incorporation, averaged 4 kg N_2O ha^{-1} for the organic system compared with 5 kg N_2O ha^{-1} for a conventional system. Also in Europe, Petersen et al. (2006) tracked N_2O emissions from five rotations sequences[12] and found N_2O emissions were lower from the organic than conventional crop rotations, ranging from 4.0 kg N2O-N ha^{-1} to 8.0 kg N_2O-N ha^{-1} across all crops as total N inputs increased from 100 to 300 kg N ha^{-1} yr^{-1}.

In the US, Pimentel et al. (200 5) examined the comparative average energy inputs (in millions of kilocalories ha^{-1} yr^{-1}) for corn and soybeans grown under three cropping systems; (i) an animal manure- and legume-based organic; (ii) a legume-based organic; and (iii) a conventional system, from 1981 to 2002. Fossil energy inputs averaged approximately 30% lower for both organic production systems than for conventional corn. Robertson et al. (2000), in the Midwest USA, compared the net global warming potential (GWP) of conventional tillage, no-till, low input and organic management of a corn soybean-wheat system over 8 yrs. After converting the combined effects of measured N_2O production, CH_4 oxidation and C sequestration, plus the CO_2 costs of agronomic inputs to CO_2 equivalents (g CO_2 m^{-2} yr^{-1}) none of the systems provided net mitigation, and N_2O production was the single greatest source of GWP. The no-till system had the lowest GWP (14), followed by organic (41), low input (63) and conventional (114).

Cavigelli et al. (2009) reported on GWP calculations for a no-till (NT), chisel till (CT) and organic (Org3) cropping systems at the long-term USDA-ARS Beltsville Farming Systems Project in Maryland, USA. Also calculated was the greenhouse gas intensity (GHGI=GWP per unit of grain yield). The contribution of energy use to GWP was 807, 862, and 344 in NT, CT, and Org3, respectively. The contribution of N_2O flux to GWP was 303, 406, and 540 kg CO_2e ha^{-1} y^{-1} in NT, CT and Org3, respectively. The contribution of change in soil C to GWP was 0, 1080, and -1953 kg CO_2e ha^{-1} y^{-1} in NT, CT and Org3, respectively. GWP (kg CO_2e ha^{-1} y^{-1}) was positive in NT (1110) and CT (2348) and negative in Org3 (-1069), primarily due to differences in soil C and secondarily to differences in energy use among systems. Despite relatively low crop yields in Org3, GHGI (kg CO_2e Mg $grain^{-1}$) for Org3 was also negative (-207) and significantly lower than for NT (330) and CT (153). Org3 was thus a net sink, while NT and CT were net sources of CO_2e. The authors concluded that common practices in organic systems including soil incorporation of legume cover crops and animal manures can result in mitigation of GWP and GHGI relative to NT and CT systems, primarily by increasing soil C.

Meisterling et al. (2009), also in the US, used a hybrid LCA approach to compare the global warming potential (GWP) and primary energy use involved in the production process (including agricultural inputs) plus transport processes for conventional and organic wheat production and delivery in the US. The GWP of a 1 kg loaf of organic wheat bread was found to be about 30 g CO_2e less than that for a conventional loaf. However, when the organic wheat was shipped 420 km farther to market, the two systems had similar impacts. Organic grain yields were assumed at 75% of conventional average yields of 2.8 t grain/ha. Soil C storage potential was assumed the same for both systems and was omitted as a mitigation credit. Comparing just the farm level production and not including transport, the GWP impact of producing 0.67 kg of conventional wheat flour (for a 1 kg bread loaf), was 190 g CO_2e, while the GWP of producing the wheat organically was 160 g CO_2e. Tillage in the organic system accounted for 600 J of energy (or 42 g CO_2e) compared to 450 J (or 32 g CO_2e) for the conventional system. By comparison, N and P fertilizer production added a total of 820 J (or 57 g CO_2e) to the GWP total of the conventional system. N_2O emissions from soil were assumed to be a large contributor to GWP of both systems and were rated as equivalent at 96 g CO_2e. As noted by these authors there is the greatest uncertainty with respect to soil C storage and N_2O emissions (uncertainty ranges were greater than the calculated GWP difference between the two systems) and 'uncertainty and variability related to these processes may make it difficult for producers and consumers to definitively determine comparative GHG emissions between organic and conventional production'. Notably, when the transport of wheat was shifted to primarily rail, the life cycle GWP impacts were considerably decreased compared to truck transport.

Among categories of emissions given in the Holos model and noted above, the highest uncertainty also is associated with direct soil N_2O emissions and indirect soil and manure N_2O emissions (Little et al., 2007). In support of the assumption of Meisterling et al. (2009) of similar N_2O emissions from both organic and conventional wheat production systems, Carter et al. (2009), after directly measuring N_2O emissions in spring, summer and fall-winter from a conventional and three different organic winter wheat production systems, found N_2O emissions related to a given amount of grain was similar in all systems.

The meta analyses of direct and indirect energy inputs, GHG fluxes and C sequestration on 33 German organic and conventional commercial cropping farms conducted by Kustermann and Hulsbergen (2009), that concluded that E use was 2.75 times lower per unit area (785 kg CO_2e ha^{-1} vs. 2165 kg CO_2e ha^{-1}) in the organic operations than conventional, has been cited above.. Gomiero et al. (2008) in their meta-analysis, drew upon three studies of winter wheat cropping systems in Europe, also reported in Stolze (2000). CO_2 emissions per land basis (kg CO_2/ha) were lower in the organic systems by an average of 50%, while emissions per unit of grain production (kg CO_2/ha) were found to be lower in two of the studies (by 21%) and greater in one (by 21%).

Deike et al. (2008) in Germany compared, using data from a long-term replicated field experiment (1997–2006), one organic farming treatment (OF) and two integrated farming treatments (IF). Averaged across all years and crops, the E inputs in OF (8.1 GJ ha^{-1}) were 35% lower than in the IF systems (12.4 GJ ha^{-1}). The largest shares of energy input in IF were diesel fuel (29%) and mineral fertilizers (37%). Mineral nitrogen (N) fertilizers represented 28% of the total energy input in the IF systems. Halberg et al. (2008), examined five European studies comparing energy use under conventional and organic farming, including some cash crop (grains and pulses) operations and concluded that energy use is usually lower in organic farming compared with conventional farming methods, both per hectare and per unit of crop produced.

Nemecek (2005) reported in the study by Niggli et al. (2008) found, after analyses of data from two long-term comparative cropping systems studies in Europe, that the GWP of all organic crops was reduced by 18% per unit product compared to the conventional production systems.

In a recent study in Spain, Alonso and Guzman (2010) compared 78 organic crops and their conventional counterparts. About 25% were comparisons for arable crops including wheat, peas, barley, oats, rice and broad bean. Primary data were obtained via direct surveys carried out at farms throughout Spain. The results indicated that non-renewable energy efficiency, at 8.27 MJ per MJ input was higher in organic arable farming compared to 6.70 MJ per MJ input for conventional arable farming, whilst the consumption of non-renewable energy was lower. Notably this difference between production systems was much greater for arable crops than all other sectors, including field and greenhouse vegetables, and fruit production. The authors conclude that an increase in the land area dedicated to organic farming would considerably improve the energy sustainability of Spanish agriculture.

In summary, while only a few Canadian studies have been conducted, the strong consensus of the data, across a range of jurisdictions and crops, indicates organic field cropping systems (grains, grain legumes, oilseeds and forages) require less energy and improve energy efficiency, both per hectare and per unit product, compared to conventional arable production systems, and provide improvements above our suggested threshold of 20%. A subset of these studies (although none are Canadian) have assessed field cropping systems for GWP (see summaries above for Robertson et al. 2000; Nemecek 2005; Gomiero et al. 2008; Kustermann and Hulsbergen 2009; Meisterling et al. 2009; Cavigelli et al. 2009). Here again, while conclusions are less definitive then for E use, and given the qualifiers noted regarding the uncertainty associated with N_2O emissions and variation in study methodology and assumptions with respect to soil C storage, and N_2O emissions from legumes etc., the consensus of the studies reviewed here suggests organic field crop management also improves GWP both per ha and per unit product when compared to conventional production.

Summary table 1

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Hoeppner et al. 2006	Manitoba, Canada	Comparative field trial	E use (MJ/ha) E efficiency (MJ per MJ input)	50%	20%
Zentner et al. 2009	Sask., Canada	Comparative field trial	E use (MJ/ha) E efficiency (MJ per MJ input)	51%	24%
Pelletier et al. 2008	Canada	LCA (of conversion)	CO_2e / ha CO_2e / ha	61% 23%	
Robertson et al. 2000	US	Comparative field trial	GWP (g/m^2)	64%[1]	
Pimental et al 2005	US	Comparative field trial	Non-renewable E use (MJ/ha)	30%	
Cavigelli et al. 2009	US	Comparative field trial	E use (CO_2e/ha) GWP (CO_2e/ha) GWP (CO_2e/unit grain)	57% 69%[2] 42%[3]	
Miesterling et al. 2009	US	LCA	GWP (CO_2e)/ kg bread)	16%	
Nemecek 2005 (in Niggli et al 2007)	Europe	Comparative field trials	GWP (CO_2e) per unit product	18%	
Kustermann and Hulsbergen 2009	Germany	Meta-analyses	E use (CO_2e/ha)	64%	
Gomiero et al 2008	Europe	Meta-analyses (incl 3 wheat studies)	GWP (CO_2e / ha) GWP (CO_2e / kg grain)	50% 21% (2 studies)	21% (1 study)
Deike et al 2008	Germany	Modeling from long term trial	E inputs (GJ/ ha)	35%	
Alonzo and Guzman 2010	Spain	Meta-analyses of survey data	E efficiency (MJ per MJ input)		24%

[1] Note: The no-till system surpassed the organic, however, with GWP of only 14 compared to the organic at 41, and conventional at 114.

[2] When compared to a no-till treatment this gain is 51%.

[3] When compared to a no-till treatment this gain is 61%.

Livestock (including pasture / forage as appropriate)

For animal production, fewer studies have been conducted and the comparisons are more difficult because of the dramatic differences in operations, particularly for hogs and poultry. There is tremendous scope, for expanded Canadian research on organic livestock systems and GHG emissions.

Beef

Beef production systems are well known to be much less efficient than crop production in terms of E, requiring seven times as many inputs for the same calorie output (Smil, 2001). Correspondingly, GHG emissions are reported as greater in beef production than poultry, egg and hog production, milk and crops. As noted by Sonnesson et al. (2009d), however, there is usually great variation in the results of studies assessing the net GHG impact of beef both because of methodological differences, system boundaries, and differences in production systems.

Niggli et al., (2008) summarized from studies by Bos et al. (2007), Nemecek, (2005), Oko-institut, (2007), and Kustermann et al. (2008) and suggested that net GHG emissions from beef production are in the range of 10 kg CO_2e per kg meat product compared with 2 – 3 kg CO_2e per kg for poultry, egg and hog production, 1 kg CO_2e per kg for milk and typically less than 0.5 kg CO2 equivalents per kg for crop production systems.

Sonesson et al. (2009d) reports, from a compilation of published studies from Europe, Brazil and Canada, a higher range (14-32 kg CO_2e per kg meat product). The one Canadian study included is that of Verge et al. (2008). In this and all the cited studies methane emissions account for 50-75% of total GHG emissions. As noted by Niggli et al (2008) and others, however, while the methane emitted by ruminants is the major limitation of their use, by allowing efficient use of often marginal land they play a critical role in global food security as the unique ability of ruminants to digest roughage from pastures allows marginal land to be effectively utilized.

In Ireland, Casey and Holden (2006) undertook a 'cradle-to-farm gate' LCA approach to estimate emissions per kg of live weight (LW) leaving the farm gate per annum (kg CO_2 per kg LW yr^{-1}) and per hectare (kg CO_2 ha^{-1} yr^{-1}). Fifteen units engaged in suckler-beef production (five conventional, five in an Irish agri-environmental scheme, and five organic units) were evaluated for emissions per unit product and area. The average emissions from the conventional units were 13.0 kg CO_2 per kg LW yr^{-1}, from the agri-environmental scheme units 12.2 kg CO_2 per kg LW yr^{-1}, and from the organic units 11.1 kg CO_2 per kg LW yr^{-1}. The average emissions per unit area from the conventional units was 5346 kg CO_2 ha^{-1} yr^{-1}, from the agri-environmental scheme units 4372 kg CO_2 ha^{-1} yr^{-1}, and from the organic units 2302 kg CO_2 ha^{-1} yr^{-1}. GWP increased linearly, both per hectare and per unit animal liveweight shipped as either farm livestock stocking density, N fertilizer application rate, or concentrates fed increased. The authors concluded that moving toward more extensive production, as found in organic systems, could reduce emissions per unit product and area and live weight production per hectare would be reduced.

Flessa et al. (2002) reported on a German research station comparison of two beef management systems; one a conventionally managed confinement fed system, the other an organic pasture based system. For both systems N_2O emissions, mainly from soils, accounted for most (~60%) of total GHG emissions, followed by CH_4 at 25% of total. Combined GWP per unit land base was 3.2 Mg CO_2e per hectare and 4.4 Mg CO_2e per hectare for the organic and conventional systems respectively. When compared per unit product (i.e. per beef live weight of 500kg), yield related GWP failed to differ between the two systems, primarily as productivity was approximately 20% greater for the confinement based system, although emissions were also higher overall.

Peters et al. (2010) in Australia using an LCA analyses considered three scenarios; (1) a sheep meat supply chain in Western Australia, (2) a beef supply chain in Victoria , Australia producing organic beef, and (3) a premium export beef supply chain in New South Wales which includes 110-120 days at a feedlot. Data was collected over two separate years for each supply chain. GHG emissions were estimated including all aspects of red meat production such as on-farm energy consumption, enteric processes, manure management, livestock transport, commodity delivery, water supply, and administration. The study found that organic production may use less energy than conventional farming practices, but may result in a higher carbon footprint, as the additional effort in producing and transporting feeds appeared offset by efficiency gains of feedlot production, even though the feedlot stage accounted for 22% of the total GWP of the beef supply chain.

The report by Sonesson et al. (2009d) noted above, notes that few systematic studies are available providing data on the GWP impact of different beef production systems in Sweden. Data on GWP per unit product, however, is presented by Sonesson et al. (2009d) from three studies of organic, 'ranch systems' and Swedish 'average beef' systems respectively, conducted by the same group of researchers (Cederberg et al. 2000, 2004, 2009). GWP impact averaged 22, 24 and 28 kg CO_2e per kg meat for organic, ranch and average production systems respectively.

Summary table 2

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Casey and Holden 2006	Ireland	LCA	GWP (CO_2e / ha) GWP (CO_2e / kg meat)	57% 15%	
Flessa et al. 2002	Germany	Comparative systems study	E use (CO_2e / ha) GWP (CO_2e / ha) GWP (CO_2e / kg meat)	16% 27% 0%	
Peters et al 2010	Australia	LCA	E use (MJ/kg meat) GWP (CO_2e / kg meat)	3%	9%
Sonneson et al. 2009d	Sweden	2 LCAs	GWP (CO_2e / kg meat)	21%	

Very limited analysis is available for this sector, particularly from North America, on which to base a conclusion. While organic beef production appears to reduce GWP per hectare this is not consistently evident when calculated per unit of meat product. Numeric results specifically on energy use and efficiency were difficult to segregate from net GWP impacts presented in the studies available, but tended to trend towards an improved outcome per landbase and per unit product under organic management.

Dairy

A modeling study in Atlantic Canada examining 19 different dairy production scenarios found that a seasonal - grazing organic system was 64% more energy efficient and emitted 29% less greenhouse gases compared with the average of all other analyzed systems (Main, 2001; Main et al., 2002). A different study comparing non-organic seasonal grazing compared with confined dairying did not find such significant differences between the two systems, suggesting that organic practice provides some significant efficiency opportunities (Arsenault et al., 2009). This study conducted a life cycle assessment (LCA) of dairy systems in Nova Scotia to compare environmental impacts of typical pasture and confinement operations. Data on material and energy inputs and outputs of these systems were obtained from local researchers and industry, and life cycle impacts in 11 categories were quantified. Use of concentrated feeds, N fertilizers, transport fuels and electricity were dominant contributors to environmental impacts. Somewhat surprisingly, grazing cows for five months per year (typical of pasture systems in Nova Scotia) had little effect on overall environmental impact. Scenario modelling suggested, however, that prolonged grazing is potentially beneficial. Compared with total confinement, a seven-month grazing scenario performed better in seven of the environmental impact categories evaluated with greatest potential improvements associated with acidification potential, ozone depletion potential, human toxicity and fresh water ecotoxicity. In contrast, land use was the only category in which an increased reliance on pasture is predicted to result in a marked increase in environmental impact.

A recent study of 15 organic dairy farms in Ontario found that farm nutrient (NPK) loading (imports-exports) and risk of off-farm losses to air and water are greatly reduced under commercial organic dairy production compared with more intensive confinement based livestock systems in eastern North America (Roberts et al. 2008). However, livestock density (and farm N surplus) on the organic farms varied and increased self sufficiency of feeding decreased. As noted below, farm N surplus has been suggested as a proxy for farm net GHG emissions per hectare (Oleson et al., 2006). How much these differences in management approach, compared with farm management system (organic vs. conventional), influence farm GHG and E use is unknown. This question is a central focus of a new current Organic Science Cluster project under Environmental Stewardship entitled ‘Modeling farm scale energy and nutrient efficiency, and GWP, as affected by management’. Using the new Holos whole-farm system GHG calculator, this project will characterize the relationship between intensity of organic dairy farm management, nutrient flows, legume BNF, energy use and GHG emissions. Energy use will be determined both as direct sources (fuel and power use on farm) and indirect sources (manufacture of fertilizer and herbicides). Direct measurements of N_2O emissions and legume BNF from long-term organic rotation trials and selected farm sites will be used to validate and improve model estimates (coefficients).

Olesen et al (2006) used the whole farm model, FarmGHG to generate data for model conventional and organic dairy farms, located in five European agro-ecological zones, to generate data on relative GHG emissions from both production systems. Farms were assumed to have the same land base of 50ha and, in each region, to achieve the same milk yield per cow. Farm systems differed in livestock density (LD); with LD taken as 75% higher on the conventional farms compared to the 100% feed self-sufficient organic farms. The livestock on the farms contributed an average of 36% of total emissions while fields contributed about 39%. Among the GHG, in this study N_2O and CH_4 dominated, accounting for an average of 49% and 42% of total farm emissions. Interestingly, the study found emissions at the farm level could be readily related to either the farm N surplus or the farm N efficiency, both of which are relatively easily measured compared to direct GHG measurements. GHG emissions per hectare (Mg CO_2e/ha) increased with production intensity (i.e. LD) and thus farm N surplus, for both types of farms and were thus usually higher for conventional dairy farms. GHG emissions per unit milk product (or metabolic energy, kg CO_2e/kg milk), however, were inversely related to farm N efficiency.

Bos et al (2007) assessed E use and GHG on organic and conventional model dairy farms in the Netherlands. Model farms were designed on the basis of current organic and conventional farming practices. Notably, on all dairy farms, indirect energy use was much higher than direct energy use with concentrates contributing the largest share to total energy use (~30%). Total energy use per ha increased with increasing milk production per ha, which was linked to stronger dependence on imports and higher animal densities. Energy use per ha, averaged over all conventional dairy farms (75 GJ per ha), was almost twice as high as that of all organic farms (39 GJ per ha). Energy use per Mg of milk produced ranged from 3.6 to 4.5 GJ on the organic farms and from 4.3 to 5.5 GJ on the conventional farms. Similarly energy use per ha, energy use per Mg of milk was positively correlated to milk production per ha. Average energy use per Mg of milk on the organic farms was approximately 0.9 GJ lower than on the conventional farms, i.e. 19% of the average energy use on the conventional farms. Thus energy use and total GHG emissions per Mg of milk in organic dairy farming were found to average approximately 80 and 90%, respectively of that in conventional dairy farming.

Thomassen et al. (2008) in the Netherlands conducted a detailed ‘cradle-to-farm-gate’LCA analyses, including farm environmental impact with respect to GHG and pollution impacts on water quality (i.e. eutrophication). As also reported above by Oleson et al (2006), N_2O and CH4 accounted for the bulk of emissions. In the conventional system CO_2, N_2O and CH_4 accounted for 29%, 38% and 34% of total GHG, compared to 17%, 40% and 43% respectively for the organic dairy farm system. Results indicated improved environmental performance with respect to energy use and eutrophication potential per kg of milk for the organic compared to conventional farms (3.1 vs 5.0 MJ per kg FPCM respectively). On the other hand, farming systems failed to differ with respect to GWP per unit milk produced. Overall recommendations from this study included reducing use of concentrates with a high environmental impact and reducing whole farm nutrient surpluses.

It should be noted that the studies of Oleson et al (2006), Bos (2007) and possibly Thomassen et al. (2008) may have overestimated N_2O emissions associated with legume nitrogen fixation (a key component of organic farm systems) as older IPCC coefficients and methodology were used in these studies. Notably, in Bos (2007) the methodology attributes ‘N_2O emissions originating from within the farm as from use of fertilizers, incorporation of crop residues and **nitrogen fixation**' while the study of Oleson et al (2006) also estimates N_2O emissions as a proportion of all N inputs to the field, 'including crop residues and **BNF**'. Oleson et al. (2006) note, however, that a better understanding of N_2O emissions and other N losses from fields is needed. Notably, actual N_2O emissions, directly measured on four prototype organic and conventional farms to validate model estimates, differed the most from estimated on the organic farms.

Falchowsky and Hachenberg (2009) conducted a review of nine European studies reporting GHG emissions from conventional and organic dairy farms, and discuss at some length the gaps and uncertainties in the data. While one study (Hass et al 2001) reported equivalent GWP per unit milk product (kg CO_2e / kg milk) for five of the studies organic systems resulted in greater GWP (ranging from a 1% - 27% increase), while organic reduced (ranging from 5% - 8%) GWP in the remaining three studies.

Gomiero et al. (2008) reviewed a number of European studies that report on comparative energy consumption and efficiency by organic and conventional dairy systems. Both energy consumption per land base (GJ/ha) and unit crop product (GJ/t) were reported as consistently lower in the organic compared to conventional dairy systems (ranging from 23-69% lower GJ/ha and 8% to 54% lower GJ/t). Using data from the study by Haas et al (2001) and also Lunstrom (1997) GWP also per hectare is reported as reduced under organic, but not when compared per unit product.

Organic ruminant livestock farms differ also from conventional with respect to the cross-breeding and management goals, which, as less intensive systems, often result in improved animal longevity. As noted by Niggli et al (2008) methane emissions can thus be reduced, when calculated on the total lifespan of organic cows. As comparative data on relative longevity across dairy production systems is limited, this consideration has yet to be included in farm system GWP comparisons.

In a recent Austrian study, Hortenhuber et al (2010) conducted a 'life-cycle chain' analyses of eight different dairy production systems representing organic and conventional farms located in alpine, upland and lowland regions. Notably, and rather innovatively, the authors include an estimate for GHG impacts of the estimated land use change (LUC) required to produce concentrates (which ranged from 13% to 24% of total feed intake for various farms) such as soybean production replacing tropical forests. Nitrogen fertilizer was assumed not used on any farms, and used only partially during external production of concentrates. About 8% of total GHG for the conventional farms was attributed to LUC associated with concentrates. In general, the study found that the higher yields per cow and per farm for the conventional farms did not compensate for the greater GHG produced by these more intensive systems, with organic farms on average emitting 11% less GHG (0.81-1.02 kg CO_2e / kg milk compared to 0.90 to 1.17 kg CO_2e / kg milk).

Sonesson et al. (2009e) summarized a review of LCA studies from ten OECD countries which found emissions up to the farm gate ranged from 1.0-1.4 kg CO_2e /kg milk. While there were minor differences between conventional and organic farms the contribution of each GHG differed. In general, organic systems had higher methane emissions per kg milk but lower emissions of N_2O and CO_2 per unit product. Sonesson et al. (2009e) also elaborates a protocol for dairy farms for the Swedish Climate Labelling for Food scheme, focusing on individual operations (whether conventional or organic) rather than the organic sector as a whole. Notably, however, many of the proposed criteria were within a general organic approach to dairying, such as: (i) a minimum of 70% of the feed must be grown on the farm ((ii) concentrates with low GWP values must be used (i.e. a preference for locally grown concentrates) (iii) annual analyses of N flows on the farm etc.

On balance, organic dairy systems appear to reduce energy use and improve energy efficiency both per unit landbase and per kg of milk produced, and the results available pass, on average, our threshold of 20%. With respect to GWP per unit product there is no consensus in the data available to suggest organic dairy systems management is significantly beneficial. It must be noted, however, that Canadian and North American data is particularly scarce with respect to comparative studies assessing E and GWP impact of dairy management systems.

Summary table 3

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Main 2001	Atl. Canada	Modeling of farming systems	E use (GJ/kg milk) GWP (CO_2e/kg milk)	64% 29%	
Olesen et al. 2006	Denmark/EU	Comparison of model farms	Mg CO_2e/ha kg CO_2e/kg milk		
Bos et al. 2007	Netherlands	Comparison of model farms	E use (GJ/kg milk) GWP (CO_2e/kg milk)	20% 10%	
Thomassen et al. 2008	Netherlands	LCA	E use (MJ/kg FPCM) GWP (CO_2e/kg FPCM)	38% 0%	
Falchowsky and Hachenberg 2009	EU	Review of nine studies	GWP (CO_2e/kg milk)	0% (1 study) 5-8% (3 studies)	1-27% (5 studies)
Gomiero et al. 2008	EU	Review of five studies	E use (GJ/ha) E use (GJ/kg milk) GWP (CO_2e/kg milk)	23-69% 8-54% 0%	
Hortenhuber et al. 2010	Austria	LCA	GWP (CO_2e/kg milk)	11%	
Sonneson et al. 2009d	Sweden	Review of LCAs	GWP (CO_2e/kg milk)	0%	

Hogs

Organic hog production may generally be the least energy efficient of the major animal systems (Kumm, 2002), possibly because of frequently lower than optimal levels of pasturing hogs, inappropriate breeds for organic systems, and not finding the most efficient roles for hogs in mixed farming operations. For example, hogs can play a useful role in weed control post – harvest or field renovation (Honeyman, 1991) and even compost aeration[13], with the potential to therefore reduce energy expenditures for weed control.

In a comparison of conventional, natural (Red Label) and organic hog production in France, Van der Werf et al. (2007) found, using a detailed LCA, that organic systems produced the lowest emissions of methane and carbon dioxide on a per ha basis, but not a 1000 kg pig basis, for which it was significantly outperformed by conventional production on nitrous oxide and carbon dioxide emissions. Only in methane production did it maintain a reduction over conventional, but the natural system performed even better. Two Swedish LCA studies, in contrast, found emissions in the organic operations to be 50% less than this French study and concluded that reduced growth rates, inefficient feed production and composting of manure, with subsequent low nitrogen use efficiency and higher ammonia and indirect nitrous oxide emissions, likely explain the different results (Sonesson et al. 2009a). However, emissions / kg meat were higher in the organic studies compared to most of the conventional operations. Similar results were found for MJ / kg meat. Degre et al (2007) also looked at 3 comparable Belgian systems (organic, free-range and conventional) and found GHG emissions (CO_2e) / pig were the lowest for the organic system followed by free-range and conventional, with nitrous oxide the preponderant gas. Organic system emissions were 87% of conventional, with slurry from conventional operations having much higher emissions than straw litter in the organic system. However, organic performance was inferior in some of the other environmental criteria assessed.

Williams et al (2006), modeling UK systems, did in contrast find lower energy use and lower emissions on a per tonne basis (13% fewer total MJ used and 11% lower GWP100 emissions), but with 1.73 times greater land requirements per tonne of production.

Halberg et al. (2008) modeled standard LCAs on 3 different Danish organic hog systems and compared the results with the literature on conventional operations (Halberg 2008). They found higher levels of GHG emissions (CO_2e/pig) on all organic operations because of higher nitrous oxide emissions and lower feed conversion efficiencies, but concluded that they were C-sequestration associated with the organic rotations included in the calculations (11-18% reductions in CO_2e/pig), 2 of the 3 organic operations would outperform the conventional one (Halberg 2008, Halberg et al. 2010).

Comparing the different conclusions of their work with those of Van der Werf et al. (2007), Halberg et al. (2010) concluded that “methodological differences makes a direct comparison between the two studies problematic. The French study also found that organic pig production had a better environmental performance compared with conventional when calculated per ha but worse when calculated per kg pig product. But they did not include differences in the soil carbon sequestration as in our study.”

Low meat yields of pork may be more efficient in terms of the ratio of human edible meat: human inedible feed. It is reasonable to postulate that too much reliance on high production will lead to crossing the ideal threshold ratio of meat: human inedible feed such that a low ratio should be flagged as likely to be unsustainable.

Sonesson et al. (2009a) concluded that although there are only a limited number of high quality studies on hogs, there was sufficient information to set out a workable protocol for the Swedish Climate Labelling for Food scheme, focusing on individual operations (whether conventional or organic) rather than the organic sector as a whole.

The current version of Holos, as it assumes hog barn capacity is full year round, is not designed for comparison or organic versus conventional hog production systems (Little et al. 2008).

Summary table 4

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Van der Werf et al. 2007	France	LCA	CH_4 / ha	69%	
			N_20 / ha		33%
			CO_2 / ha	13%	
			CH_4 / pig	46%	
			N_20 / pig		242%
			CO_2 / pig		58%
Sonneson et al. 2009a	Sweden	2 LCAs	CO_2e / kg meat	6% (1 study)	2-35% (6 studies)
			MJ / kg meat	1-4% (2 studies)	18-41 (4 studies)
Degre et al (2007)	Belgium	Expert ranking	CO_2e / pig	13%	
Williams et al. 2006	UK	Modelling	MJ/tonne	13%	
			GWP100/tonne	11%	
Hallberg et al. 2010	Denmark	Modelled LCA	GHG100 / kg & C sequestration	4-33% for 2/3 org. farms	7% for 1/3 org. farms

On balances, comparison results were mixed for hogs, but somewhat more consistently favourable results for organic operations when measuring GHG emissions / ha and kg. Including carbon sequestration appears to create more positive comparisons for organic as well. However, many of the studies favouring organic did not pass our 20% threshold.

Poultry

There is some evidence that organic poultry systems are more efficient. For example, one solar emergy study, emergy being the solar (equivalent) energy required to generate a flow or storage (Odum, 1996), found that organic production resulted in a higher efficiency in transforming the available inputs into final products, a higher level of renewable input use, greater use of local inputs, and a lower density of energy and matter flows. Emergy flow for the conventional poultry farm was 724.12×10^{14} solar em joule/cycle, while for the organic poultry farm, it was just $92.16 \times 10^{14.}$ The main reasons were the lower emergy cost / kg meat produced for poultry feed, veterinary drugs and cleaning/sanitization of the poultry barns between production cycles. Interestingly, the positive results were not a function of differences in housing systems (Castellini et al., 2006).

Williams et al. (2006) used standard LCA to model typical conventional and organic production scenarios in the UK. They found that organic poultry meat and egg production increased energy use by 30% and 15% respectively. Although organic feeds had lower energy requirements, these savings were outweighed by lower bird growth rates. GWP from organic poultry meat production was up to 45% higher than conventional production. Bokkers and de Boer (2009) reached similar conclusions when examining Dutch organic and conventional operations; not necessarily surprising, given that some of their modelling was based on the work of Williams et al., (2006). The key comparative factor is the high feed conversion rates obtainable in conventional production. Sonesson et al 2009b, from their review of 5 European studies including Williams et al., found that nitrous oxide emissions from conventional feed, associated with N fertilizer and soil losses, presented the greatest opportunities for savings in well designed organic systems. The design of barn heating systems would be another significant area for efficiencies, especially in hatcheries.

The current version of Holos is not designed for comparison of organic versus conventional poultry production systems as it assumes poultry barn capacity is full year round (Little et al. 2008).

Comparative data on poultry production is particularly sparse, especially for eggs (Sonesson et al., 2009c).

Summary table 5

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Castellini et al., 2006	Europe	Emergy analysis	solar em joule/cycle (per kg meat)	87%	
Williams et al. 2006	UK	LCA modeling	Energy use/kg meat Energy use/egg		30% 15%
			GWP/kg meat		45%
Bokkers and de Boer 2009	Netherlands	Multiple sustainability indicator modelling	Energy use / kg meat		30-59%

In conclusion, only on a solar emergy basis would organic currently appear to be more energy efficient that conventional production (though it doesn't pass our 20% threshold), but this is an area with very limited analysis.

Horticultural crops

Vegetables (including potatoes where they are a part of a vegetable operation)

Four European potato studies summarized by Gomiero et al. (2008) found that, on a per ha basis, organic fossil energy use was from -27 to -48% of conventional, but on a per kg basis -18 to +29%. Gomiero et al also reported on input/output per unit of yield studies, with 3 German studies reporting organic at +7-+29. A US study, however, reported more positive results for organic production, at -20 to -13 of conventional (Pimentel et al., 1983). Williams et al (2006), reporting on per tonne comparisons in the UK, found little difference in energy use for potato production and slightly lower GHG emissions in organic production, the largest difference being in reduced direct nitrous oxide emissions.

Using an non-renewable energy balance approach that included embodied energy of inputs, structures and machinery[14], Alonzo and Guzman (2010) reported on numerous Spanish organic / conventional comparisons. Across 13 vegetable case comparisons[15], they found non-renewable energy was 41% lower in the organic operation. Organic systems relied to a much greater extent on renewable energy which was critical to the overall analysis since the organic systems used more energy of all kinds than the conventional operations.

Using a hybrid input-output economic and LCA analysis, Wood et al. (2006) concluded that organic vegetable production in Australia had about 50% of the energy intensity of conventional vegetable production (measured as MJ/$Australian). The main energy reductions were associated with on-site energy use and fertilizer.

A British MAFF study (MAFF 2000) found that energy input / ha in organic production energy use was 54 percent of conventional potatoes, 50 percent for carrots, 65 percent for onions, and 27 percent for broccoli. On a per tonne basis, results were less dramatically positive, essentially 16-72 percent lower across a range of vegetables.

Data on CH_4 and N_2O emissions suggest similar results to those for CO_2 though data are relatively more limited (Stolze et al., 2000). Interim research results from Atlantic Canada field trials comparing organic and conventional potato rotations found lower nitrous oxide emissions per hectare in the organic plots using biological N sources (Lynch et al., 2008). These results concur closely with a European study by Petersen et al. (2006) who found N_2O emissions were lower per hectare from various organic than conventional crop rotations (some including potatoes).

Bos et al. (2007) used a model farm approach and compared one organic and one conventional arable farm on clay soil (both growing potato, sugar beet, wheat, carrot, onion and pea) and one organic and conventional vegetable farm on sandy soil (leek, bean, carrot, strawberry, head lettuce and Chinese cabbage). They calculated direct and indirect energy use and GHG emissions with no net accumulation or depletion of soil C. Emissions of GHGs were expressed as 100-year GWP (CO_2 equivalents). Energy use (MJ/ton) in organic head lettuce, potatoes and leaks was higher than conventional, in the 20-40% range depending on the crop, but dramatically lower in organic sugar beets and peas, and slightly lower in beans.

Summary table 6

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Gomiero et al. 2008	Europe	4 studies using variety of methods	Potatoes, fossil energy use / ha Potatoes, fossil energy use / kg	27-48% 18%	 29%
	Germany	3 Energy input / output	Potatoes / kg		7-29%
Pimentel et al. 1983	USA	Energy	Potatoes / kg	13-20%	
Williams et al (2006)	UK	modelling LCA	Energy use / t potato GHG / t potato	0 Slightly lower	
Alonzo and Guzman 2010	Spain	13 vegetables, non-renewable energy balance	MJ input	41%	
Wood et al. 2006	Australia	Vegetables, hybrid LCA & economic input/output	MJ/$ Aus	50%	
MAFF 2000	UK	Direct and indirect energy inputs	Energy input / ha – potato carrots onions broccoli	46% 50% 35% 73%	
			Energy input / t Potato, carrots, onions, broccoli, leeks	16-72%	
Bos et al. (2007)	Netherlands	Model farm	(MJ/ton) lettuce, potatoes and leaks Sugar beets, peas Beans		20-40%
De Bakker et al. (2009)	Belgium	LCA	GWP$_{100}$ CO$_2$e / ha Leeks GWP$_{100}$ CO$_2$e / kg Leeks	67% 53%	
Oko-institut (2007)	Germany		CO$_2$e / kg Vegetables Potato, tomato	 15% 31%	

Similar results were found by Bos et al. (2007) for GHG emissions (CO_2e / ton), though the range of differences was narrower compared to energy use. However, there is some concern about overestimating N_2O emissions from legumes in this study (see dairy section above) although this is possibly a small overall contributor to farm budgets.

De Bakker et al. (2009), examining leeks in Belgium in a full LCA analysis, concluded "that the total climate change indicator score, Global Warming Potential, GWP100 is 0.094 kg CO_2-equivalents/kg leek for the conventional system and 0.044 kg CO_2-equivalents/kg leek for the organic system, revealing conventional leek production to have a substantially higher impact on climate change. The GWP depends mainly on the use of fossil fuels for on farm activities, energy use for the production of inputs and emissions of N_2O connected to the on-farm nitrogen cycle." Diesel use per kg leek was actually higher in organic, but the on-farm nitrogen cycle and synthetic fertilizer use in the conventional system had a larger impact than fossil fuel use. The results favoured organic to an even larger degree on a per area basis, with organic production producing only 33% of conventional emissions.

An Oko-institut study conducted in Germany by Fritsche and Eberle (Oko-institut, 2007) found a range of vegetables to have 15% lower GHG emissions measured as CO_2e / kg and for tomatoes and potatoes, the reduction in GHG emissions was 31%.

In summary, with the exception of potatoes, organic vegetables show consistently lower energy use, higher energy efficiency and lower GHG emissions on a per tonne and per ha basis. Most results favouring organic exceed our 20% threshold.

Fruit

Scialabba and Hattam (2002) concluded that organic apple production in GJ/ha was 90% of conventional apple production, but 123% per ton of product. Reganold et al. (2001), from a long term Washington state trial, found that organic apple production had 14% lower energy use on a per ha basis, largely because of reductions in synthetic fertilizers and pesticides, but 7% higher on a per unit of production basis. In Europe, Geier et al. (in Gomiero et al., 2008) found even higher use in organic relative to conventional (23%) on a per product basis but comparable on a per area basis.

In a perennial orchard system in Washington State, Kramer et al. (2006) found after nine years that the organically managed soil exhibited greater soil organic matter and microbial activity, and greater denitrification efficiency (rN_2O or N_2O:N_2 emission ratio) compared to conventionally managed, or integrated orchard management systems. While N_2O emissions were not significantly different among treatments, emissions of benign N_2 were highest in the organic plots.

Using a hybrid input-output economic and LCA analysis, Wood et al. 2006 concluded that, even though on-site energy use is higher, in total, organic fruit (which kinds were not specified) in Australia had about 30% lower energy intensity than conventional fruit production.

Alonzo and Guzman (2010) for a wide range of irrigated fruits[16] (18 cases) and rainfed fruit and nut production[17] (22 cases) found non-renewable energy efficiencies (MJ input / MJ output) of 5.89 for organic and 5.48 for conventional production and 2.82 and 2.14 respectively. Organic systems relied again to a much greater extent on renewable energy.

Gundogmus and Bayramoglu (2006) examined raisin production on 82 conventional and organic Turkish farms and concluded that even though human labour inputs were higher on average for organic farms, organically produced raisins consumed 23 percent less overall energy on average than conventional production and had a better input-to-output energy efficiency ratio. Gundogmus (2006) also examined, on a largely on-site energy input/output basis, small holding apricot production in Turkey and found that conventional production, on a per ha basis, used 38% more energy than organic production systems. The organic systems also had a 53% higher output/input ratio, measured as MJ of production, even though yields were about 10% lower in the organic systems.

Kavagiris et al (2009) examined direct and embodied energy and human labour on 18 conventional and organic Greek vineyards and found significantly lower energy inputs and GHG emissions in the organic operations, although emissions were only measured in a limited way related to diesel fuel consumption. Energy productivity, measured as grapes produced/inputs, was equivalent.

A joint LCA - emergy analysis was used to compare the environmental impacts of growing grapes in a small-scale organic and conventional vineyard in Italy (Pizzigallo *et al.,* 2008). Despite 20% lower yields in the organic system GHG emissions for organic grapes were lower than for conventionally grown ones. Fuel and steel consumption were respectively 2 and 6 times greater on conventional operation. This result counterbalanced the higher yields in this system. However, this LCA was limited in that production-related fertilizer emissions were only calculated for the conventional system, and field-level fertilizer emissions in both systems were excluded entirely. Using a bottle of wine as the functional unit in a partial LCA (limited by data availability), Point (2008) found effectively no differences in GWP potential between NS conventional and organic production, at two levels of organic yields, one at 20% below conventional, the other at par.

In summary, and as summarized in summary table 7 below, fruit results are mixed on both an energy use and GHG basis. Organic is slightly favoured on a per ha basis, but not generally so on a per tonne of production basis, unless the study takes a full emergy analysis approach or examines non-renewable energy use efficiency. In only a few studies does organic performance exceed our 20% threshold.

Greenhouse

The energy efficiency of organic vs. conventional greenhouse production has not been well studied, complicated by both differences in yield and technology preferences. Although organic yields appear to be lower, there is also evidence that organic producers frequently use less energy intensive greenhouse technology which may offset per output differences (Azeez, 2008). In the Alonzo and Guzman (2010) study of greenhouse vegetables, the differences between production systems were negligible when both used the same greenhouse technology as the high fixed energy use of the structures made production differences insignificant. Other studies have come to similar conclusions (Ziesemer, 2007). Williams et al (2006) found that the lower yields of UK organic tomatoes (about 75% of conventional) and the focus on more specialist varieties meant that energy use and emissions were almost double those of conventional production on a per tonne basis if the same heating and power systems were used in the greenhouses. All this explains, in part, why the BioSuisse organic standard includes a strict limitation for greenhouse heating (Scialabba and Müller-Lindenlauf, 2010). For organic greenhouse production to warrant an energy efficiency of GHG reduction brand likely means use of advanced ecological greenhouse designs or very low technology systems using waste heat from biological processes.

Summary table 7

Authors	Region	Type of study	Measure	Org < Conv	Org > Conv
Scialabba and Hattam (2002)	Europe	Numerous energy	Apples GJ/ha GJ/t	10	23
Reganold et al. (2001)	Washington, US	Energy	Apples Energy / ha Energy / t	14	7
Kramer et al., 2006	Washington, US	N_2O	Apples	0	
Geier et al. 2001 in Gomiero et al	Germany	Energy	Apples Energy / ha Energy / t	0	23
Wood et al. 2006	Australia	I/O – LCA hybrid	Fruit, energy intensity/$	30%	
Alonzo and Guzman (2010)	Spain	Non-renewable energy efficiency	Fruit, MJ input / MJ output	Organic 7-32% more efficient	
Gundogmus (2006)	Turkey	Energy I/O	Apricots, MJ/tonne	Organic 53% more efficiency	
Gundogmus & Bayramoglu (2006)	Turkey	Energy consumed	Raisins	23%	
Kavagiris et al (2009)	Greece	Energy productivity	Grapes, energy produced / inputs	0	
Pizzigallo *et al.,* 2008	Italy	joint LCA - emergy analysis	Grapes, solar emergy / l wine	34%	
Point 2008	NS	LCA	Grapes, GWP potential at 2 levels of output	0	

Issues that cross commodity lines

Tillage

Frequently, fuel usage for tillage is highlighted by organic farming critics but, as noted above in the section on field crops, fuel use increases relative to no-till operations are usually a relatively small part of total farm greenhouse gas fluxes (Robertson et al., 2000; Hoeppner et al., 2006). Dyer and Desjardins (2005) report that fuel used for farm fieldwork in Canadian farming systems typically contributes less than 10% of total on-farm GHG emissions. Dyer and Desjardins (2005) report GHG emissions for secondary tillage operations, such as discing that would require more draft power than finger weeders, as low (~ 28 kg CO_2/ha) compared to plowing (90 ~ 28 kg CO_2/ha) and between two to three times that for spraying (~ 10 kg CO_2/ha). Manure spreading is also a relatively low E requiring practice.

Organic carrot and potato production have been identified in several European studies as having high energy inputs per unit of output because of mechanical weeding (Ziesemer, 2007). In a limited number of systems, such as potatoes with mechanical weeding, the increased energy from tillage may mean energy use in the entire system is roughly comparable, but in most other production systems, even with tillage, energy use is often half of conventional (Stockdale et al., 2001). Organic farmers have frequently shifted from deep to shallow tillage (e.g., finger weeders) and these shallow tillage operations likely do not consume more fuel than herbicide applications, and can frequently be lower users of energy, especially when herbicide manufacturing is included in the energy balance (Clements et al., 1995).

Zentner et al. (2004) found that although use of minimum and zero tillage practices provided significant energy savings in the form of fuel and machinery, these savings were largely offset by increased energy expended on pesticides and N fertilizers. In a study conducted in the Parkland region of the Canadian Prairies, they compared non-renewable energy inputs and energy use efficiency of monoculture cereal, cereal-oilseed, and cereal-oilseed-pulse rotations, each four years in length and each managed using zero, minimum and conventional tillage practices. Total energy use over a 12-yr period was largely unaffected by tillage method, but differed significantly by crop rotation.

Composting

There is some Canadian evidence (Pattey et al., 2005) that composted cattle manure has significantly lower GHG emissions on balance than stockpiled manure and slurry, largely because of much lower methane emissions.

In the study of Bos et al. (2007), energy requirements for imported organic manures were restricted to those for transport and application only and a ‘zero energy’ price for organic manures themselves was assumed. Consequently, E use was lower for a crop fertilized mainly with organic fertilizers than for a crop fertilized mainly with mineral fertilizers. On farms, manure (or compost) application is a relatively low fuel and E cost (< 10 kg CO2/ha) when compared with tillage operations (> 80 kg CO2/ha and > 28 kg CO2/ha for plowing and discing respectively) and harvesting (> 33 kg CO2/ha) (Dyer and Desjardins, 2005).

Soil C Sequestration

To produce a gain in carbon storage, a management practice or system must (a) increase the amount of carbon entering the soil as plant residues or (b) suppress the rate of soil carbon decomposition. Organic farmers generally add either more organic C or a more diverse range of materials relative to conventional and no-till operations. In their meta-analysis, Mondalaers et al (2009) did find statistically significant higher levels of soil organic matter on organic farms, but also reported on numerous studies that did not find convincing evidence of differences, largely they believe because of methodological limitations. There is evidence that adding diverse materials with suitable C:N ratios also creates a more stable pool of organic material (Willson et al., 2001; Marriot and Wander, 2006). This was confirmed in a long-term USDA study in Maryland directly comparing organic production with no-till conventional production. The study showed that organic farming built up soil C better than conventional no-till because use of manure and cover crops more than offset losses from tillage (Teasdale et al., 2007). Animal manure, the diversity and C: N ratio of organic additions, and the decay rate may be important to this process (Marriot and Wander, 2006). Cavigelli et al. (2009) for example, found improved GHG intensity (or GWP per unit grain yield) and GWP for an organic compared to no-till and chisel till systems in Maryland, USA, to be due primarily to increased soil C[18] under the organic system compared to chisel or no-till systems. Sanchez et al. (2004), in a long-term (7 yr) study of comparative grain management systems in Michigan, found the enhanced ''substrate diversity'' of a transitional organic management system that combined green manures and compost enhanced both short ('active'') and long-term soil C and N pools.

Research teams at Michigan State University compared corn-soybean-wheat systems under conventional tillage, no-till, low input and organic systems (with legumes, but without animals and manure). Using CO_2 equivalents (g/m^2/year) as their measure for systems comparisons, they found that no-till had the lowest net Global Warming Potential (GWP) (14), followed by organic (41), low-input (63) and conventional tillage (114) (Robertson et al., 2000). The Michigan study also concluded that perennial crops (alfalfa, poplars) and successional communities all had much lower emissions and in fact most were net C sinks.The no-till system superiority over organic was a result of higher soil C sequestration (-110 to -29). However, there is some debate about the extent to which no-till systems actually sequester carbon and to the type of organic matter stored and its permanence. In some studies, soil C content increases within the top 7.5 cm of the soil profile, but results in no changes over the entire profile (Wander, 1998; Needelman et al., 1999; Poirier et al., 2009). The Michigan study only measured soil C changes in the top 7.5 cm, so the C sequestration benefits of no-till may be overestimated relative to organic systems. No till, because it increases moisture in the profile, may also be increasing N_2O emissions in drier environments (Mummey et al., 1998; Smith et al., 2000).

Studies from the US mid-west, examining corn, soybeanand wheat systems showed that longer rotations involving legumes leave farms better able to withstand drought (Welsh, 1999). One series of studies from the University of Nebraska concluded that the longer rotations reduced the risks of suffering through a bad year, and had less variable net returns (Helmers et al,, 1986). The Rodale trials showed 25-75% greater corn and soybean yields in drought years (Drinkwater et al., 1998; Pimentel et al., 2005). These longer rotation systems have performed consistently as well or better than short corn - soybean rotations. Similar results have been produced in non-irrigated organic potato production in Maine (Mallory and Porter, 2007). These results appear to be due to some combination of root development, associations with soil organisms and soil tilth (Lotter, 2003). Organic matter, especially in more loamy soils, can improve soil aggregation. Aggregation creates more pore space for root movement.

The traditional view is that the kind of organic matter is less significant than the quantity, but the more digested organic matter fractions appear to be significant for these processes - microbial gums and mucilages, low molecular weight fulvic acid molecules, and fats and waxes (MacRae and Mehuys, 1985). There appears to be a high correlation between increased soil carbon levels and very high levels of mycorrhizal fungi that help retard organic matter decay through the binding action of the glomalin they produce. These mycorrhizal fungi were more prevalent and diverse in organically managed systems than in soils relying on synthetic fertilizers and pesticides (LaSalle and Hepperly, 2008).
More recently, Teasdale et al. (2007) conducted a 9-yr comparison of selected minimum-tillage strategies for production of corn, soybean, and wheat at USDA ARS Beltsville, MD. The four management systems compared included: (i) an organic system using cover crops and manure for nutrients and reliant on chisel plow for tillage and post-planting mechanical cultivation for weed control; (ii) a standard no-tillage system with recommended N inputs and herbicides; (iii) a no-till cover crop (hairy vetch and rye) based system with reduced herbicide and N inputs; and (iv) a no-tillage crownvetch living mulch system. Despite the use of tillage in the organic regime, and the lowest corn yields (28% below the conventional no-till system), at the end of the study soil total carbon and nitrogen concentrations were greatest at all depth intervals (to 30 cm) in the organic compared with that found for all other systems, and 19 and 23%, respectively, greater than that achieved for the no tillage system. This creates greater system resilience and less need to the kinds of synthetic N additions that increase nitrous oxide emissions. This was also reflected in improved soil productivity under the organic plots. In a uniformity trial conducted at the end of the study in which standard no-till corn was grown on all plots, yield gains of 18% were recorded on the organic plots.

Recent surveys of Canadian grain producers suggest tillage may be offset by increased organic matter return. Nelson et al. (2010) documented, through mail out survey responses (n=225) from organic and conventional grain growers on the Canadian prairies, that while organic farmers used more tilled summerfallow than conventional farmers ((52% vs. 6%)), they also had more forages and green manures in rotation (66 vs. 64% and 84% vs. 6%, respectively). The authors recommend further research to determine the net effect of these practices on soil C while developing alternatives to summerfallow suitable to organic production.

In Atlantic Canada organic potato farms utilize extended (5-yr) rotations including legume cover crops compared with much more frequent cropping of potatoes (and associated tillage) in conventional production systems (Angers et al. 1999; Lynch et al. 2008). Recent studies suggest these rotations confer marked benefits to soil organic matter and soil health including micro- and macro-fauna. In a study conducted on four farm sites over 2 years, indices of soil health including earthworm abundance and biomass and soil microbial biomass appeared to benefit particularly from these extended rotations, recovering from marked reductions during potato cropping to levels found in adjacent permanent pastures only after 3 to 4 yrs after potatoes (comprising 1 yr of grain followed by forages) (Nelson et al. 2009). Soil organic C levels were also sustained at all sites (~ 30-38 Mg C ha^{-1} in the surface 0-15cm across all sites and rotation phases) with no significant change during the potato phase or relative to the reference fields.

Despite these positive results, innovative approaches to tillage reduction are being explored in organic production. Hepperly (2008) reported on the substantial additional SOC gains from a 'biological no-till' system that combines cover crops and a crop roller system at the Rodale Institute when compared to conventional no-till, and standard organic management. No-till systems for organic vegetable production are also being explored (Dorais, 2007). In Canada research efforts are underway within the Organic Science Cluster to test no-till systems for organic grain production (M. Entz, pers comm. 2010).

Another key issue for carbon sequestration is reaching steady state permanence, usually 15-33 years depending on soil and management, and then avoiding measures that subsequently contribute to C declines. There are also significant debates about how to account for regional variability, measurement uncertainties, process uncertainties, identifying real additionality, reducing leakages, and appropriate pricing of stored carbon (Smith et al., 2007). All this suggests organic farmers should not necessarily count on the development of well functioning carbon sequestration markets in the short term to finance improvements to their operations. Niggli et al. (2007), however, argues that soil C sequestration is very cost effective, can be achieved relatively quickly, and because of its many ancillary benefits, should be given as a credit for improved soil management practices, as are common on many organic farms. Currently SOC credits are excluded from Clean Development Mechanisms and World Wildlife Fund for Nature programs.

The influence of livestock systems and the management of permanent grassland in particular on potential SOC storage has been assessed much less when compared with comparative studies of cropping systems' influence on SOC. Organic ruminant livestock producers are required under organic standards to rely on forage-based livestock feed including, in season, management of grazed pastures. Improved grazing management, including the use of legumes, and decisions on grazing intensity and stocking rate as practiced by organic farmers, can be a cost effective option that promotes substantial SOC gains on the extensive acreage of often degraded permanent grasslands in Canada (Franzlubbers et al. 2000; Lynch et al. 2005, Niggli et al., 2008).

The Holos model does include a Land Use – soil C storage and emissions calculator. An important input is the change in percentage of perennial crops on the farm (leys).

Energy Offsets

To what extent might energy offsets from energy crops, residues and biogas production create a more favourable energy balance for organic farms? These questions must be examined against comparable conventional farming energy strategies. A review by MacRae et al. (2010) suggests that energy crops and residues have a much more limited role on organic farms compared to conventional ones, because of the need to use organic material for nutrient and soil building purposes, and the high demand for organic food targeted to human markets. Similarly, biogas production will likely play a more limited role, given the limited amount of manure that can typically be directed towards on-farm biogas, and the degree to which anaerobic digestion is discouraged in organic standards[19]. Although energy offsets, even in a limited capacity, can improve the overall GHG reduction and energy efficiency of an organic operation, they are likely to be relatively smaller benefits than could arise from conventional operations.

Studies of widespread organic adoption

There are only a few studies examining the energy implications of widespread adoption of organic farming systems. A Danish study of wholesale national conversion to organic farming found 10-51% reductions in net energy use relative to 1996 conventional agriculture, depending on the scenario of wholesale conversion. Scenarios varied by yields of animal and crop production and extent of self-reliance in animal feed. As organic yields improved, there was greater potential for efficiencies. These reductions in net energy use were associated with significant reductions in greenhouse gas emissions, particularly nitrous oxide emissions (Dalgaard et al., 2002; Dalgaard et al., 2003).

Few studies of the GHG and GWP implications of more widespread adoption of organic systems in Canada have been undertaken. The Pelletier et al. (2008) study was summarized above. An unpublished and less complete analysis by World Wildlife Fund Canada (2002), based particularly on assessments by Robertson et al. (2000), reported total GHG reductions from limited conversion scenarios at 1.225 Mtonnes of CO_2 equivalents, a significant amount given AAFC's target at the time of the analysis for reductions from agriculture of 10-20 Mtonnes (MacGregor and Boehm, 2004).

Consumption – related considerations

Here we consider consumption related issues that could impact on the interpretation of the conventional-organic production differences.

Though not well studied in Canada, some recent work suggests that dairy and eggs, fresh and frozen meat and prepared foods were the biggest food household expenditure contributors to GHG emissions in 2003 (Statistics Canada, 2009). Using US analyses that are more robust, we elaborate on some of these findings.

Processed foods

In the US, processed foods account for 82- 92% of food sales (Pimentel et al. 2008). Many foods require minimal, or what is called primary processing, to be edible and to increase nutritional value, while others go through extensive secondary and tertiary processing that adds to convenience, though not necessarily nutritional value. In fact, much secondary and tertiary processing reduces some nutritional components, requires sophisticated packaging, and is very energy intensive. In recent years, households have effectively transferred energy use from the home to such processors (Canning et al. 2010). Pimentel et al. (2008) propose that the most effective method for decreasing energy inputs is to dramatically reduce consumer demand for these secondary and tertiary processed products that require large energy inputs. For example, a can of diet soda has only 1 kcal of food energy, yet requires about 500 kcal to produce, with a further 1,600 kcal to produce the 12 oz. aluminum can. Thus, 2,100 kcal are invested to provide zero to 1 kcal of consumable energy (Pimentel and Pimentel, 2008). In addition, the energy input for transportation must be taken into account.

Animal products

Some analysts see the other population explosion – livestock – as a huge threat to global sustainability (Weis, 2007). Land use changes to accommodate livestock production, manure production, animal feed grown with synthetic nitrogen fertilizer, direct emissions from animals themselves, transport, chilling and heating in the processing and consumption chain may account, directly or indirectly, for 18-51% of total GHG emissions on the planet (Steinfeld et al. 2006; Goodland and Anhang, 2009). An EU study concluded that half of all food-related emissions in the EU are associated with meat and dairy products (European Commission, 2006). It would appear that encouraging more plant-based diets, especially in combination with organic production, would pay significant dividends. Animal-based protein foods are 2-100 times more energy-intensive than plant-based protein foods, depending on the production system and commodity (Carlsson-Kanayama, 1998).

Eliminating livestock is not, however, a viable option, since they can play very important ecological roles on farms. But it is important to optimize both human and animal feeding systems by maximizing ruminant feeding on forages/grass, while monogastrics feed on residues and seeds of non-dominant crops. Other countries have more optimal balances. For example, the national share of grain fed to animals is only 5% in India, compared to 60% in the US (Smil, 2001:237). Crop residues and wastes must be better maximized. One effective component of that strategy is to increase feeding on oil seed crush, processing residues, and lower quality feed grade crops. As well, more research on pasturing hogs and poultry can help determine optimal livestock levels on pasture. Reducing feed losses will improve overall system efficiency. While elimination may not be appropriate, significant reductions in consumption of livestock products may reduce environmental stressors and improve human health.

Related to this is the need to rationalize selection of animals. At present, much of the focus in organic meat production is on cattle, partly because of the pasture-related opportunities, partly because of current market realities. Pigs, however, have 40% lower energy requirements than would be anticipated from their size, largely because of low basal metabolism. Thus, there is an energy logic to favouring hogs over cattle, which have much higher basal and reproductive metabolism. Pigs also tolerate a wide range of environments. Dairy animals do, however, have a favourable conversion ratio for milk.

As discussed above, how to best take advantage of these biological realities has yet to be fully explored in organic hog systems. Chicken and eggs are next most efficient on the energy conversion scale, suggesting that they warrant more attention in landscape level planning for energy efficiency. Ultimately, fish are much more efficient feed converters than farm livestock. Thus, it makes sense over the longer term for the organic sector to devote more attention to ecological herbivorous and omnivorous fish production systems.

Wasted food

By some estimates, up to 40% of what gets planted and raised is never eaten. Waste is generated at all stages of the supply chain – at harvest, during storage, distribution, retail, and as kitchen waste. For example, each phase of the grain handling process – from harvest to threshing, drying, storage and milling – can produce up to 10% losses, for cumulative losses of 40%. Fruit and vegetable losses run in the 10-70% range (Peters et al., 2002, 2003), though not all waste is of edible matter. But all of it, theoretically, could be used, either by humans, animals or as soil amendments. Given the immaturity of the organic waste handling system in Canada, with the exception of some provinces, most notably Nova Scotia, the system is likely not minimizing its losses.

Another type of waste arises from “unnecessary” consumption. The average person on the planet might need 2200 kcal/day (with an additional 800 kcal/day lost from production to consumption) (Smil, 2001:237). The average North American is consuming substantially more than is required for optimal health, perhaps around 3700 kcal/day (Pimentel et al. 2008). The average Canadian consumes more calories than is generally required for good health (Garriguet, 2006; Statistics Canada, 2006). A more health – oriented approach to consumption, with a focus on more equitable global distribution of food resources, would ultimately reduce the pressure to increase crop and animal yields (and the associated use of high emissions nitrogen fertilizer) and dramatically reduce food system emissions per capita.

A key place to start would be reducing junk food consumption. The average American appears to consume 33% of their total calories from junk food. According to Pimentel et al. (2008), “reducing junk food intake from 33% to 10% would reduce caloric intake to 2,826 kcal, conserve energy, and improve health “ (Pimentel and Pimentel, 2008).

Conclusions

Early in this report, we set out what needs to be in place to make organic sector wide branding a possible strategy. We discuss the results of our study in the context of those conditions.

1. Clear and significant differences exist in energy and GHG emission performance between organic and conventional operations.

Organic generally has lower energy use and GHG emissions per ha, better energy input/output ratios per unit of product, but variable results for energy use and GHG emissions per unit of product. With some variability in results for field crops, hogs and some fruits and vegetables, organic systems are consistently more energy efficient, beyond a 20% threshold, than conventional systems, measured by land area and production. Similarly, GHG emissions are consistently lower, with again some variability in those same commodities, but in more cases than energy efficiency, the 20% threshold is not passed. This is especially the case when measured on a per product basis, where results are often highly variable. Poultry and fruit, however, generally favour conventional systems, or when organic is favoured, usually not beyond the 20% threshold. The main reasons for better organic performance are the lack of use of synthetic N fertilizers and much lower use of feed concentrates. Studies consistently show that the absence of most synthetically compounded agri-chemicals in organic production is a major reason for reduced energy use and lower emissions. This is not surprising given that nitrogen fertilizers account for around 1% of total anthropogenic GHG emissions on the planet and 10% of direct agricultural emissions (Sciaballa and Muller-Lindenhauf, 2010). Williams et al. (2006) calculated that 56% of the total primary energy burden of conventional UK wheat production was attributable to mineral fertilizers and 11% to pesticides. Pimentel (2006) found similar results for US corn, 30–40% of energy use for fertilization and 9–11% for plant protection products. Their elimination from organic production significant changes energy use and emissions. Tillage in organic farming does not appear to be a significant contributor with respect to on-farm E use, in contrast to common assumptions of organic critics. The study found no consistent evidence to support the view that tillage reduces soil carbon in organic systems. In fact, the study found that the inverse is usually true, i.e. that green manures and forages increased soil C on organic farms regardless of added tillage. Equally, the criticism that organic producers are diesel farmers is not supported by the data.

2. Consistent approach in how emissions are reported. i.e. whether on a per land unit basis or product basis.

There is considerable debate in the literature about which measures are most appropriate and the variability in the comparative results means this is a significant issue that has yet to be resolved. Due to yield differences in intensive conventional production zones (ie. Europe), per product comparisons more commonly disfavour organic especially when examining GHG emissions. Although organic critics commonly argue that lower yields are sufficient reason to not support organic agriculture, many regions of the global south show better yield performance in organic compared to conventional systems (cf. Pretty and Hines, 2002). In areas where conventional farming significantly out-yields organic, it is not obvious that this conventional "overproduction" is entirely beneficial, given on-going farm financial challenges, trade distorting measures that penalize producers in less “productive” regions, and overconsumption of food in those very regions that overproduce.

3. A consistent approach to whether a credit for soil carbon sequestration is included in the estimates.

Although the comparisons consistently favour organic production, not all studies measure soil C storage. There is a mixed attitude to the permanence of agricultural soil sequestration and some reluctance to include agricultural soil sequestration in Clean Development Mechanisms (CDM) and other sequestration standards (Niggli et al., 2008). In some systems, only C sequestration appears to create a positive outcome for organic, especially when measured on the basis of output (Niggli et al., 2008) so this is significant.

4. A consistent approach with respect to N_2O emissions from biologically fixed N by legumes.

Earlier studies, using then current IPCC coefficients, likely overestimated emissions from legumes in organic systems. However, until such study results are recalculated, the implications cannot be quantified.

5. Accepted measures for determining differences.

As Mondalaers et al (2009) have concluded, no consistent approach to meta-analysis exists for organic – conventional comparisons. Our review found 5-6 main approaches to doing such studies, and the results are not always comparable. Concluded Gomiero et al. (2008:243), “Results from energy assessments are often difficult to compare because of the variety of methodologies and accounting procedures employed". Van der Werf et al. (2007) used 5 different European approaches to tease out their efficacy related to organic / natural / conventional comparisons and found significantly different results across the evaluation schemes.

6. Generally, agreement that these differences are consistently realizable; in other words that they are not so variable by time and space that no consistent patterns emerge.

Results are variable by jurisdiction, usually determined by whether the conventional comparator is an intensive or an extensive production system. This means that global comparisons are more difficult, but allow for regional ones.

7. The changes represent a permanent improvement. The presumption of such comparisons is that the gap between organic and conventional in regard to these measures remains constant.

Organic recidivism is low and the demands of annual inspection mean that most practices, once adopted for organic certification, are retained. However, debates over the permanence of soil C pools remain.

8. The differences in E and GWP between organic and conventional farms do represent an incremental gain worth promoting within the context of overall food system GHG mitigation and energy efficiency.

Assuming, as found in the US study of Canning et al. (2010) (Canadian data is sorely needed), that farm E use represents a gross average of 35% of total food chain E use and continues to increase, an improvement of 20% or more in E efficiency through organic farm management would represent a reduction in food-chain E use of 7% or more. In practice, farm E use as a proportion of total food chain E use varies widely by sector (ranging in the US study of Canning et al. (2010) from 17% to 54%), thus benefits of organic farm management to total may be even greater. Among food supply chain stages other than agriculture, the wholesale/retail stage (including cooling and packaging) and the processing stage represents similarly large contributors to the entire food supply chain, often contributing 30% or more to total E costs. Thus, and as also noted above in the section on processed foods, additional improvements in food system E use can be obtained by emphasizing reduced processing and whole foods. Organic processing protocols, through their emphasis on minimal additives, limited numbers of ingredients, and less degrading process techniques, may already offer efficiencies, an aspect that requires more study. Finally, reducing transport offers some additional, if smaller, potential for E and GHG gains (and again data for the Canadian food system is lacking) and a significant body of literature has examined relative E and GHG efficiency of various freight modes. Ultimately, it will be important for the organic sector to note that the improvements in efficiency gained at the farm level, can be lost through inefficiencies further along the chain, including processing, transport and wholesale / retail. This is particularly important in the horticultural sector in North America, with heavy reliance on trucking (higher GHG emissions / tonne than rail and ship) and product cooling all along the supply chain (see Weber and Matthews, 2008; Garnett, 2006; Masanet et al. 2008). In the study of Miesterling et al (2009), in the US discussed in the section on field crops above, the GWP of a 1 kg loaf of organic wheat bread was found to be about 30 g CO_2e less than that for a conventional loaf. However, when organic wheat was shipped 420 km farther to market, the two systems had similar impacts. Thus assuming local transport systems are efficient[20], promotion of local, whole, organic food offers the greatest gains combined in reducing E costs of providing organic food to the consumer.

Ultimately, the differences between organic and conventional production, while significant, may be relatively small compared to reductions that are possible at other levels in the food system such as through changes at a population level favouring lower levels of meat consumption (see argument put forward to Weber and Matthews, 2008). However, these farm level benefits are an incremental gain, which combined with significant improvements in processing E use and efficiency, and to a lesser degree by improvements in transport, cooling and packaging of conventional supply chains, will further add to farm scale benefits from organic management. It is worth noting that data with respect to E use in the Canadian food system is still very limited.

9. That some verification measures either at the sectoral or farm level are feasible, depending on the nature of the branding.

Measures are being introduced and guidances are being produced. Climate change inspectors exist, though such work could only be described as being in its early stages of evolution. Farm energy audits are, in some jurisdictions, being provided through provincial environmental farm plans. Documentation of all inputs and often yields regularly recorded by organic farms provides an important component of any farm scale verification system with respect to farm E use and efficiency.

In summary, our study found significant variability in the volume and type of studies examining organic vs. conventional systems (see Table 8)

Table 8. Relative availability of literature

Sector	Literature Availability**
Field crops	√ √ √ √
Beef	√ √
Dairy	√ √ √
Hogs	√ √
Poultry	√
Vegetables	√ √ √
Fruit	√ √ √
Greenhouse	√

**From all sources/locations

Only on-farm energy use would appear to offer sufficiently robust data to warrant branding, with poultry and fruit question marks given current evidence, albeit very limited, favouring conventional production or not surpassing our threshold of 20% organic advantage. Branding based on GHG emissions reductions, given variability in study approaches and evidence, is premature. However, with more robust data on GHG emission comparisons, and attention to the most up-to-date emission coefficients, it is likely that branding GHG emissions perha would be feasible in the medium term. The longer term challenge regarding GHG emissions per product is to either a) improve organic yields with better knowledge and farm-level performance; or b) subject conventional production to cost internalization, thereby producing market signals that encourage producers to reduce yields to less damaging levels in conventional systems. Both options will only likely produce results in the longer term.

Whether it is possible to brand based on a relatively narrow area of food system performance is an important question. Although an efficiency claim is more tenable in extensive North American production, the globalized nature of organic foods and the current reliance on imports to meet demand in the Canadian market means a claim focusing on national production is problematic. And on-farm energy use is only one piece of the climate change discussion, so isolating on-farm E use has the potential to be seen as manipulating consumers.

This begs the question of co-branding. If organic production reduces GHGs by avoiding N fertilizer[21], and local production (if goods are efficiently moved and especially if the production is organic) can reduce GHGs, and whole food consumption also diminishes GHGs by avoiding processing and packaging, then perhaps the organic sector should be looking for the sweet spot where organic, local and whole foods intersect.

This inquiry has also identified a substantial future research agenda:

- Canadian data on organic / conventional comparisons is generally limited, except in field crops and dairy. But there are major needs for studies on other livestock and horticultural products.
- System-level analyses of energy use and GHG emissions, as opposed to BMP assessments, are also deficient.
- Refining GHG co-efficients in organic operations is particularly important to garner a full understanding of organic performance.
- Organic E and GHG performance across supply chains. Few studies examine organic food from inputs through production, distribution, processing and retail. Do organic supply chains outperform conventional ones? Also, given that wasted food is a huge energy efficiency (cf. Smil, 2001), is food waste as high in organic food chains as conventional ones?
- Ultimately, there are larger questions about the GHG and energy costs of simple rotations or confined single species livestock systems, whether conventional or organic. To the extent that conventional or organic farms deviate from a baseline of good agronomic or husbandry standard practice, they compromise capacity to avoid GHG and energy costs in the long term or become too brittle and not able to adjust as the cost of C and energy rise. It's important to better understand these dynamics.

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Endnotes

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[1] Anaerobic digestion is usually discouraged because the manure produced is viewed as suboptimal for soil organisms. Exceptions may be permitted when a converting conventional operation has already significantly invested in anaerobic systems or when the system is also generating biogas.

[2] See label at http://www.freshplaza.com/news_detail.asp?id=39542

[3] See video information at http://www.youtube.com/watch?v=ZzuWyW-t7CM

[4] In English the Technical Inspection Group, based in Germany

[5] http://www.klimatmarkningen.se/in-english/

[6] Matt Holmes. 2010. Canadian Organic Brand – Executive Summary. Ottawa: OTA.

[7] Ibid.

[8] We do not report on comparisons of food production systems involving crops not produced in Canada.

[9] Farming systems with numerous interconnected production elements woven together in the farm management scheme, as opposed to many conventional operations where components are managed somewhat distinctly, without a full sense of their inter-relationships.

[10] LCA was defined in 2006 by the International Organization for Standardization (ISO) 14040 as a 'compilation and evaluation of the inputs and outputs, and the potential environmental impacts of a product system throughout its life cycle'.

[11] Arnqvist and Wooster (1995) define a meta-analysis as a specific set of statistical quantitative methods that are designed to compare and synthesize the results of multiple studies.

[12] Five rotations sequences used for N2O measurement (adapted from Petersen et al. 2002)
OR1 Spring barley Barley-pea/grass Rye Grass Grass
OR2 Grass-clover Barley/grass Pea + oat Wheat –
OR3 Winter wheat Beet roots Barley Alfalfa –
OR4 Potatoes Oat/grass Grass Maize –
OR5 Permanent meadow
CO1 Spring barley Barley-pea/grass Rye Grass Grass
CO2 Grass-clover Barley/grass Pea + oat Wheat –
CO3 Winter wheat Beet roots Barley Alfalfa –
CO4 Potatoes Oat/grass Grass Maize –
CO5 Permanent meadow
OR=organic, CO=conventional

[13] See practices at Polyface Farm, http://www.polyfacefarms.com/products.aspx

[14] The energy consumption of machinery and implements was attributed to four factors: production of raw materials, manufacture, repair and maintenance, and fuel consumption.

[15] Asparagus, lettuce, melon, celery, cauliflower, potato, broccoli and onion

[16] Apples, pear, plum, tangerine, orange, mango, grapes, bananas, fig, peach, apricot and avocado

[17] Olives, vineyards, hazelnut and almond

[18] Note that it is well established that C sequestration rates will diminish over time and approach a steady state.

[19] Sonesson et al (2009b) suggest chicken manure might be an exception.

[20] Interesting work on new, more E and GHG efficient, local distribution systems is underway.

[21] Note that saving on the transport of inputs is also a very significant contributor to GHG improvements, and usually not calculated among organic efficiencies (see Weber and Matthews, 2008).