Comparing energy use and GHG mitigation potentials in organic vs. conventional farming systems

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Summary

This paper discusses key realities, challenges and opportunities related to the energy efficiency and greenhouse gas emissions reduction potential of organic food and farming systems. Issues at both the farm and organic system level are examined. Although data is limited for some crops and animals, organic systems consistently demonstrate greater energy efficiency / land unit and unit of production compared to conventional operations. These positive results are usually attributable to the absence of synthetic fertilizers, particularly nitrogen, and synthetic pesticides. However, comparisons are somewhat less positively in favour of organic in some commodities when contrasting energy efficiency against unit of food output, largely because of the yield differences between some organic and conventional systems in Europe. Such results suggest that the efficiency of organic systems can only improve with research on optimizing yields / inputs.

Similar results have been found for greenhouse gas mitigation. Organic systems produce fewer emissions per unit area and unit of production. However, as with energy efficiency, emissions per output are less strongly favour organic, except it would appear under difficult weather conditions when organic production can significantly outperform conventional. Organic systems also appear to have greater carbon sequestration potential, with the possible exception of some no-till systems. However, there is significant debate in the literature about both the quantity and quality of carbon stored in no-till systems, leading some to conclude that current no - till estimates are overstated. On balance, organic systems would appear to have greater adaptive potential than many conventional systems.

However, the energy efficiency and GHG mitigation potential of organic systems can be significantly improved, following both farm-level and sector-wide strategies. In general, farm – level strategies are of three kinds: improving energy efficiency and reducing GHG emissions, storing carbon and generating biofuel offsets. But the specific conditions of organic farming, relative to conventional production, limit the number of currently promoted strategies that can fit into organic operations. The Canadian organic sector has slowly been improving its capacity for collective initiatives, presenting the possibility that energy efficiency could be an area addressed at a national scale by focusing on landscape-wide production and consumption management issues. By their nature, most of these are medium to long term strategies, and many of them have significant biological and institutional research components. Which strategies to pursue in the medium term may be determined by how much energy will be available and of what kind. The more constrained the world is to produce petroleum-related inputs, the more favourable biological processes, of the kind favoured in organic systems, will look.

Integrating energy crops into organic farming also presents some unique challenges relative to conventional systems. Consistent with organic certification standards requiring whole farm conversion, for most farms, energy production should be a coherent and integrated complement to organic food production. Given current organic food markets, and existing resource and input constraints, energy crops should ideally occupy land not well suited to food production, provide good soil cover, return significant levels of

organic matter, have limited fertility and pest management requirements, require minimal attention from farmers during busy periods, and enhance biodiversity.
There appears to be a very limited case for organic farms to produce feedstock for ethanol or biodiesel in the near term, for reasons of both farm economics and broader organic system requirements. The case against conventional grain-based ethanol is strong, and even stronger in an organic farming scenario, since organic farmers generally reduce corn area post – conversion because of its demands on soil resources. Canola-based biodiesel is not an option since organic canola production has largely been eliminated by GE contamination, and what organic canola is grown commands such a significant premium that it makes no sense to produce it for energy. Soybean-based biodiesel would also not appear to be a viable option, as prices for human-market soybeans are generally high and there is a significant shortage of affordable feed grade organic soybeans. On-farm biodiesel production, using simple processing technologies, may be an option if the crop is poor. Cellulosic ethanol is a better fit, except that the capital costs are significant, leading to centralized production facilities, and the technology has yet to be fully commercially proven. There also remains some dispute about the energy efficiency of many cellulosic ethanol processes.

Some of the energy crop and biomass systems that appear to best fit in organic systems include mixtures of C4, C3 and leguminous grasses and forbs, switchgrass (including overwintering for spring harvest), and short rotation forestry of willow, poplar or alder. In the near term, using these three feedstocks for solid rather than liquid fuels appears to be a more viable option because of energy conversion efficiencies, GHG reductions, and the technology required for liquid biofuel production. Ideally, ash from combustion of solid biofuels is returned to farms. Such production, however, may only be suitably targeted to about 5% of the farm area.

Although such energy crops do not require significant levels of fertilization, and should not be provided organic material best suited to food crops, there have been proposals to use currently prohibited sewage sludge on energy crops. In ecological theory, there is a sound rationale for using properly processed human manure (humanure) and urine on plants, but there exists a huge gap between the potential purity of individual household humanure (assuming the family is healthy and not requiring significant medication) and the end products arising from current residential human waste collection and treatment systems. The failure to separate residential and industrial sewage and the nature of the sewage treatment processes explain, in part, the prohibition on sewage sludge use in organic standards. Under current rules and existing realities, it might only be in some newly designed eco-communities where properly composted human waste, or source separated urine from people in good health, would be “clean” enough to use on organic farms.

In some European countries, including Denmark, where there has been some success reducing heavy metal and persistent organic compounds in sewage sledge, a reconsideration of the prohibition on sewage sludge has been proposed for energy crops. With careful management and modest application rates, there is some evidence from Scandinavian studies that use of cleaner sludge may not unduly increase contaminants in short-rotation forestry soils. However, much would likely need to be done to improve the quality of Canadian sludge before such a proposal could be seriously considered.

Priority areas for future research to improve energy efficiency and GHG mitigation potential of organic systems include:

- Yields in monogastric organic animal production systems and horticultural crops
- Improving the design, nutrient effectiveness, and photosynthetic efficiency of organic crop rotation and tillage systems
- Better matching of animal types, stocking rates and agronomic functions to nutrient and energy flow dynamics of organic operations
- Energy efficiency of composting systems
- Optimizing root / microbe interactions
- Mechanisms for landscape level planning of organic production to match the biophysical and moisture resources of each region
- Soil restoration using organic farming
- Reducing food waste in organic supply chains
- Linking the organic movement to structural efforts to reduce obesogenic environments
- Linking dietary choices with the development of the organic sector, including reducing animal product and processed food consumption
- Reducing reliance on long distance truck and air freight for organic food distribution
- Addressing looming labour challenges in organic agriculture (and the Canadian food system more generally)
- Studies of widespread adoption of organic farming systems and their national GHG mitigation implications
- Improving the agronomic performance of targeted energy crops

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Introduction

This paper discusses key realities, challenges and opportunities related to the energy efficiency and greenhouse gas emissions reduction potential of organic food and farming systems[1]. Issues at both the farm and organic system level are examined.

The first and second sections summarize the existing data on energy efficiency and GHG emissions of organic vs. conventional systems. Such system comparisons do pose analytical difficulties, given that finding comparable operations is often challenging, especially in livestock systems. In comparison with conventional operations, organic farms typically have more diverse crop rotations, lower stocking rates and different land base requirements, all of which affects an energy comparison. Consequently, farming system level comparison 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. There are also significant challenges related to energy accounting and the boundaries applied to the system being studied. Gomiero et al[2] 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, 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 LCA approach
- the extent to which the study addresses whether externalized costs are internalized

The third section builds on this comparative analysis and other sources to identify both the farm and system level changes that bring about greater energy efficiency and reduced GHG emissions. The strategies are organized using an Efficiency-Substitution-Redesign (ESR) analytical framework that helps identify strategies that can progressively be implemented[3]. Efficiency-stage strategies involve minor changes to existing operations that help to create a more efficient farming system or that remove an obstacle to participation by producers. Efficiency strategies are less likely than other types to demand too much of producers, costs are not usually prohibitive, and no complicated technical analyses are necessary.

Substitution strategies focus on the replacement of one measure by another, or on the addition of a parallel measure with a similar structure but different intent. These are usually more expensive and complex to implement.

The redesign concept is rooted in a desire to mimic ecological processes. Redesign requires the longest time to implement and the greatest changes to human and physical resource use. The unique benefit of redesign, which makes it the ultimate objective of farm-scale and system transition strategy, is the identification of permanent solutions to problems. Such redesign is, however, unlikely to be achieved until processes have progressed through the efficiency and substitution stages. To ensure that the potential to redesign is not compromised, efficiency and substitution strategies must be assessed in light of their ability to support the redesign process.

The second half of the third section looks at issues beyond the farm. In recent years, the organic sector in Canada has done a better job at strategic planning and improving its capacity for sector-wide initiatives. This section addresses efficiency matters that require system wide planning and implementation.

In the fourth section, the question of how energy crops can be integrated into organic systems is examined. Although much has been written about energy crops, little of it is directly pertinent to organic operations because of their unique characteristics. Given the current disputes over use of good crop land and annual crops for ethanol and biodiesel that compete with production for human food, this discussion focuses on the potentials for "non-competitive spaces and plants" on organic farms.

In the fifth section, the use of sewage sludge to close nutrient loops is examined as an addendum to system efficiency issues related to biofuel production. Although sewage sludge is not currently permitted in organic standards and likely will not be until major changes to human waste collection and treatment are made, some analysts are pondering the merits of applying sewage sludge to lands growing biofuel crops.

Finally, the last section offers suggestions for future work.

Part I – reviewing the literature on energy efficiency in organic farming systems, with a particular emphasis on organic vs. conventional comparisons

In their recent meta-analysis of a wide range of global organic vs. conventional comparisons, Gomiero et al.[4] 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 favourable to organic.

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 some evidence that organic poultry systems are more efficient. For example, one solar emergy[5] study 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. 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[6]. Organic hog production may generally be the least energy efficient of the major animal systems[7], 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.

However, several other studies show that lower yields in poultry meat and eggs produce less favourable assessments on a per unit of production basis[8]. This reality has led Stockdale et al.[9] to conclude that when calculating energy input per unit of physical output, the advantage of organic systems has usually been reduced. However, in more extreme weather conditions, the organic systems have consistently outperformed the conventional ones, tipping the comparative balance more in favour of organic production (see section II for more on this phenomenon). Such results suggest that the efficiency of organic systems can only improve with research on optimizing yields / inputs.

The Gomiero et al. study did not include any Canadian work, although there are a few studies that would appear to confirm the conclusions of that analysis:

- A 12-year organic vs. conventional cropping trial in Manitoba examining 2 rotations showed that energy use was 50% lower in the organic systems studied, with the greatest energy efficiency (measured by input/output) coming from an organic wheat - alfalfa - alfalfa - flax rotation. The absence of inorganic N fertilizer was the main contributor to reduced energy inputs and greater efficiency[10].
- 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[11]. 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[12].
- 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 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."[13] 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.

Such results are broadly consistent with wider angle analyses comparing high and low input agriculture systems. In these studies, the low-input systems (a category into which organic production falls) almost always outperform high input systems in energy efficiency[14].

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[15].

Part II – GHG mitigation and adaption: the role of organic farming

The main Canadian agriculture emission sources[16] are:

- For carbon dioxide (CO_2): breakdown of soil organic carbon, consumption of fossil fuels, use of synthetic pesticides and fertilizers
- For methane (CH_4) : liquid manure tanks, animals
- For nitrous oxide (N_2O): inefficient, ineffective or inappropriate use of nitrogen fertilizers resulting in significant nitrogen release to water and air

N_2O and CH_4 are priorities for reduction, since agricultural soils are now thought to be net CO_2 sinks but N_2O and CH_4 emissions continue to rise[17]. 42% of GHG emissions were associated with the livestock sector[18], particularly, most CH_4 emissions which are associated with animal digestion (almost all of it from beef and dairy) and manure management (also N_2O and CO_2 emissions). The most significant emissions from the cropping sector are associated with synthetic nitrogen fertilizer (12 Mt CO_2eq in 1996 and now higher).

To reduce these kinds of emissions, the International Panel on Climate Change (IPCC) has concluded that, in general, mitigation practices should: a) enhance sustainable production; b) have additional benefits for farmers, including profitability; and c) generate products that are suitable to consumers[19]. Unfortunately, in Canadian agricultural policy circles, this advice has not been well heeded. The focus rests primarily on Best Management Practices (BMPs), rather than farming systems, and the four pillars of global warming strategy – emissions reduction, carbon sequestration, biofuel offsets and adaptation – are treated largely distinctly, as policy makers fail to find synergies among the four through adoption of suitable farming systems[20].

A. Emissions reduction

From a systems perspective, organic farming usually leads to reductions in emissions and meets the IPCC's criteria for success. It also provides opportunities to integrate the four pillars of global warming strategy. 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)[21], often has lower animal stocking rates which contribute to lower methane emissions generally, consumes less energy and water overall, and has higher percentages of farm area in perennial crops (including pasture) and shelterbelts[22].

Similarly to their review of energy efficiency studies, Gomiero et al.[23] 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 by 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[24]. Pelletier et al in their study of Canadian canola, corn, soybeans and wheat found that organic yields had to be unrealistically below conventional before emission reductions were eliminated[25].

Composting and tillage are sometimes offered up as reasons why organic farming should not be supported as a greenhouse gas mitigation strategy. Frequently, fuel usage for tillage is highlighted by organic farming critics. In a limited number of systems, such as potatoes with mechanical weeding, the increased energy from tillage may mean energy use is roughly comparable, but in most other production systems, even with tillage, energy use is often half of conventional[26]. Organic farmers have frequently shifted from deep to shallow tillage (e.g., finger weeders) and these shallow tillage operations do not necessarily consume more fuel than herbicide applications. Fuel use increases relative to no-till operations are usually a relatively small part of total farm greenhouse gas fluxes[27].

Data on CH_4 and NO_2 emissions suggests similar results to those for CO_2 though data is relatively more limited[28]. Interim research results from Atlantic Canada field trials comparing organic and conventional potato rotations found lower nitrous oxide emissions in the organic plots using biological N sources[29].

B. Combining reductions, sequestration and adaptation

There is some additional empirical research from North America on organic farming systems that demonstrates significant opportunities for greenhouse gas emission reductions, combined with greater adaptive capacity in the face of climate variability and significant carbon sequestration potential.

Drinkwater et al. in their study contrasting conventional and alternative longer course organic corn - soybean cropping systems in Pennsylvania, found that longer rotations involving leguminous plants did not necessarily add more total organic matter to the soil, but because of the lower carbon to nitrogen ratio, additions resulted in greater organic carbon sequestration and improved soil physical properties[30]. As well, they cut nitrogen losses in half compared to the conventional system. A recent update of their study (5 more years of data, to 23 years in total) showed that the organic rotations are actually accumulating 15-28% more organic carbon than the conventional trials[31]. Rodale Institute scientists[32] have concluded that organic can remove 40% of CO_2 if practiced on all tillable acres, but other studies reviewed in Gomiero et al.[33] suggest that CO_2 storage rates are reduced over time, that soils essentially get saturated and a steady state is reached. Consequently, the Rodale estimate is likely overly optimistic.

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/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)[34]. 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. 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[35]. 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.

The debate about the merits of no-till is also connected to the type of organic matter stored and its permanence. Other studies from the US mid-west, examining corn, soybean, wheat systems, showed that longer rotations involving legumes leave farms better able to withstand drought[36]. 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[37]. The Rodale trials showed 25-75% greater corn and soybean yields in drought years[38]. These longer rotation systems have performed consistently as well or better than short corn - soybean rotations. This result appears to be due to some combination of root development, associations with soil organisms and soil tilth[39]. 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[40]. 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[41].

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. What's critical is that the carbon enters at a rate that exceeds the decomposition rate. Organic farmers generally add either more organic C or a more diverse range of materials relative to conventional and no-till operations. There is evidence that adding diverse materials with suitable C:N ratios also creates a more stable pool of organic material[42]. 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 better than conventional no-till because use of manure and cover crops more than offset losses from tillage[43]. Animal manure, the diversity and C:N ratio of organic additions, and the decay rate may be important to this process [44].

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. Pineiro et al[45], in their review of many studies of soil organic carbon (SOC) accumulation in set aside lands, concluded that there are high but variable accumulation rates for the first 15 years, and then stable accumulation rates at half previous levels for the following 15 years. Accumulation is very slow for the following 80 years before reaching levels found under native vegetation. Compounding the complications of C storage measurement associated with these timelines, 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[46]. 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.

C. Canadian estimates of GHG reductions related to more widespread adoption

Few studies of the GHG implications of more widespread adoption of organic systems in Canada have been undertaken. The Pelletier et al study was reviewed in section I. A less rigorous analysis was conducted in 2002 for World Wildlife Fund Canada[47], based particularly on assessments by Robertson et al.[48], and it came to the following conclusions:

Conversion of dairy systems in Ontario and Quebec to organic production
If 2,100 of the almost 17,000 Ontario and Quebec dairy farms**—**252,000 ha of tillable land**—**converted to organic production, GHG emissions (including offsets from increased C-storage) would be reduced by 179 ktonnes/year CO_2 equivalents**.**

Conversion of prairie cereal cropping systems to organic production
If 1 million ha of land (or about 10 % of total Prairie area) with spring wheat (including durum) currently as part of the rotation were converted to organic rotations, GHG emissions would be reduced by an estimated 260 ktonnes/year CO_2 equivalents**.**

Conversion of corn/soy/wheat cash cropping in Ontario to organic production

If 0.2 million ha of land (or about 91% of Ontario winter wheat hectarage) were converted to an organic corn-soybean-wheat rotation with winter legume cover (vetch or clover) 2 years of the 3 following corn and wheat (with no manure applied), GHG emissions would be reduced by 135.8 ktonnes / year CO_2 equivalents**.**

Conversion of Prairie beef operations to organic production

If 17% of conventionally managed cow-calf beef operations were converted to organic management (with 50% grass/legume pasture, 50% native range), GHG emissions would be reduced by a total of 649 Ktonnes/year CO_2 equivalents**.**

Total GHG reductions from these limited conversion scenarios was reported 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[49].

Part III - strategies to improve organic farming energy use and efficiency, and GHG adaption and mitigation capacity

A. Farm – level strategies

There is no end of proposals for efficiency improvements in agriculture generally[50] but how many of these are actually pertinent to systems such as organic is up for discussion. Most farm level proposals for GHG mitigation follow a best management practices (BMP) approach, rather than an integrated farming systems one. This means that proponents propose discrete practices that may fit in a range of farming systems. But many are not well suited to organic farming philosophy, operations or permitted practices and substances.

Using organic farming practices and the ESR transition framework[51] presented earlier as a filter, this section provides a broad overview of the kinds of farm – level initiatives that can help organic farms increase energy efficiency, reduce GHG emissions and sequester carbon. The strategies listed here appear to be some of the most promising based on the findings reported in sections I and II, though they certainly do not represent a complete list of possible measures. Many of the proposals have applicability beyond organic farms and are part of general proposals for improvements. In general, farm – level strategies are of three kinds: improving energy efficiency and reducing GHG emissions, storing carbon and generating biofuel offsets. The first two are addressed here and the biofuel production discussion is reserved for Section IV.

Agronomic operations:

Efficiency strategies

- Reducing field passes for operations, including use of strategic tillage, and one pass multiple operations, and or shift to shallow tillage with wide implements and guidance systems

- Reducing pumped irrigation or more efficient motors, by focusing on water efficiency of plants, landscapes and irrigation systems. Highly efficient motors and pumps can improve energy use efficiency from 30-65%.
- Avoid field crop drying with dryers[52]

Substitution strategies

- Purchasing more fuel efficient farm equipment. Here, farmers are somewhat at the whim of equipment manufacturers, with the additional complication that many find the need to purchase different equipment, sometimes of European origin, to better fit into the organic operation.
- Getting the scale right, avoiding the tendency to buy more power than is usually required.
- On-farm biodiesel production (see section IV)

Redesign strategies

- Increasing outputs with the same inputs. Real priorities are in improving yields in some horticultural crops, and hog and poultry systems.
- Efficiency of the nutrient cycle, including better management of leguminous crops, OM imports (if farms bring in biomass that is waste from other processes, that improves the net situation), and composting efficiency
- Shifting towards perennial plants, and perennial plant – animal systems

Crop system design

Efficiency strategies

- Better matching of crops to soil and moisture conditions
- Better sequencing of crops in rotation to account for the plants' abilities to extract, fix, use and pass on nutrients

Substitution strategies

- Efficiency of crop conversion of sunlight energy, including better matching of the genetics of the plant, and the design of the plant system,
- For vines and orchards, better design of the site, the layout, and the pruning to convert solar energy

Redesign strategies

- Improving photosynthetic efficiency of the crop rotation, including possibilities for better use of C4 plants

Manure management:

Efficiency

- Reducing surface area of manure management pile
- Covering all compost operations,
- More regular scraping to outdoors during cold season to reduce temperature

Substitution

- Switching from slurry to composted solid manure under cover. Composted farmyard manure has significantly lower emission rates than conventional slurry[53].
- 10-20% of originally voided N lost during farmyard storage, so improving conservation of nutrients post-voiding can pay off
- Improving manure application techniques to minimize losses

Redesign

- Extending time animals are outdoors, with manure deposited primarily on the landscape. Collecting manure is less efficient than deposit on fields. This creates a need to maximize pasture and grazing of grains and grain stubble. About 70% of cattle manure is already dropped on fields and not collected, and can only be transported 8 miles before the net energy balance is negative[54].
- Keeping compost piles cool, indoor storage may be more effective during warmer periods than outdoor.

Animal management

Efficiency

- Using probiotics, fish oil and plant extracts to reduce emissions of methane from enteric fermentation and careful diet formulation to reduce nitrous oxide emissions from manure[55]
- On-farm feeding, including improving forage quality, and minimizing concentrates

Substitution

- For chickens and pigs, longer cycles mean less energy intensity, including less frequent clean out operations
- To reduce CH_3 and N_2O emissions, additional advances can be made with improvements to animal housing systems[56]

Redesign

- Optimizing lifetime efficiency of dairy cows, rather than short-term performance, including reproductive efficiency[57]
- Selecting slower growing breeds because they are more effective in an organic system compared to conventional breeds, even though conventional breeds “outperform” in a conventional sense[58], and generally perform better on pasture. Improving forage quality and matching breeds to performance on forage is a related strategy.
- A key energy question may be how the animals relate to land quality on the farm, and the feeding / nutrient cycling regime played by the animals.

B. Larger system issues

As with many other issues, there are sector wide strategies that could improve the energy efficiency of organic supply chains. The Canadian organic sector has slowly been improving its capacity for collective initiatives, presenting the possibility that energy efficiency could be an area addressed. This section presents some of the issues that could be tackled on a systems level, inspired by, but adapted from, the work of Smil[59]. By their nature, most of these are substitution and redesign stage strategies, and many of them have significant biological and institutional research components. Which strategies to pursue in the medium term may be determined by how much energy will be available and of what kind. The more constrained the world is to produce petroleum related inputs, the more favourable biological processes, of the kind favoured in organic production, will look.

b.1 Production issues

Efficiency of land use and productivity

- There are major opportunities to make more efficient the use of existing resources: land, biological inputs, varieties and breeds. In Canada, there isn't much landscape level planning to ensure that cropping and animal production reflect the ecologically realities of a region. Such planning is more complex than just matching crops to soil types. Although some effective planning happens at the individual farm level, no organization has responsibility to promote landscape level changes that reflect landscape realities. And, of course, the competition with other land uses, particularly urbanization, makes this task more complicated.
- On a global basis, hundreds of millions of ha of existing arable land are underutilized or compromised by conventional agricultural practices. Given organic agriculture's better performance related to protecting soil resources, and greater adaptability to less suitable moisture conditions, using organic production for cropland remediation, i.e., overcoming underutilization associated with erosion or salinization, is a feasible sectoral development strategy. It also would help counter the claims that organic is not a viable production strategy because of lower yields. On a total land use basis, organic production is more efficient because it doesn't reduce the quality of the land base and requires lower levels of exogenous energy and nutrients. However, the potentially additional land requirements on a per farm basis (e.g., for greater forage production), mean again that a mechanism is required for landscape level land use shifts, beyond the decision making of individual operators. It is not feasible for the market to encourage suitable re-allocations, such as taking land out of animal production, shifting to human crops, or resuscitating less productive lands compromised by conventional practices.
- Many urban areas also have land that could be used for food production, especially if such production is coordinated to avoid competition with peri-urban producers, and for informal production. Permaculture provides a potential landscape level model for such coordination[60], with production proximate to residences focusing on "kitchen gardens".
- The focus on high optimal harvest index in conventional plant breeding may be reducing overall system efficiencies associated with the plant, and it also

increases off-farm export of nutrients, putting more pressure, in system efficiency terms, on mechanisms for closing nutrient loops on farms. Because organic farmers may make better use of the non-human edible parts of the plant- either for organic matter, for animal feed, or for bedding - lower harvest indices are desirable, and such efficiencies could be augmented with further inquiry.

Nutrient recovery and recycling

- Figuring out ways to return nutrients when organic crops are exported as animal feed (and for energy) is a priority area for investigation. It is a significant issue in certain Canadian organic commodities, for example, export of soybeans to Europe / Japan, and hay and alfalfa anywhere off-farm.
- Optimizing root / microbe interactions needs further work since there is a tremendous diversity in the microbial world that has yet to be tapped.
- Smil has predicted N efficiency improvements of 25-30% for synthetic N[61]. What levels of overall nitrogen recovery from biological sources are feasible, including gains from recycling residues, crop rotation, biological organisms, reduced tillage, and reduced soil loss? What level of applied nutrient can be absorbed by the crop in an efficient system? Can 70% absorption be achieved? Green manure nitrogen recovery is typically much higher than synthetic N (70-90% vs. 30-50%) but is spread out over much longer time horizons with usually only 5-10% available in the first following crop.

Wasted food

- By some estimates, up to 40% of what gets planted and raised is never eaten. Waste is generated at all stages in the chain, at harvest, during storage, distribution, and 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[62], though not all are of edible matter. But all of it, theoretically, could be used, either by humans, animals or as soil amendments. Is the organic handling system minimizing its losses?
- According to Smil[63], the average person on the planet might need 2200 kcal/day (with 800 kcal/day lost in from production to consumption). Additionally, the average North American is consuming substantially more than is required for optimal health, perhaps around 3500 kcal/day. How might organic advocates ultimately intersect with those working to reduce obesity and better match kcal intake to body requirements? This would ultimately reduce the pressure to increase yields.

Photosynthetic efficiency

- Continue exploration of perennial C4 plants in organic systems to maximize possibilities for photosynthetic efficiency, while also balancing potentially increased nutrient requirements. C4s, such as corn and sorghum, have not fit well in Canadian organic systems although some Canadian farms report shifting to sorghum because of increasingly droughty conditions. Other C4s may have a significant role to play in energy crops in organic operations (see section IV).

Human labour

- How can the efficiency of human labour be improved in organic? Gomiero et al.[64] concluded that there are, on average, 20% higher human labour requirements in organic systems (with significant variability across regions and field vs. horticultural crops[65]). In many nations, where labour is in ready supply, this creates employment opportunities. But in Canada, with serious shortages in farm labour (and other areas of the food system)[66], it is not clear how expanding organic production can acquire the necessary labour. Consequently, it may be that organic production requires more research on improving labour efficiency.

Animal feeding

- To optimize both human and animal feeding systems, there's a need to have ruminants as much as possible on forages/grass and monogastrics on residues, and seeds other than the dominant crops. Other countries have more indicative balances. For example, the national share of grain fed to animals is only 5% in India compared to 60% in the US. Crop residues and wastes must be better maximized and as part of that it can be effective to feed oil seed crush, processing residues, and lower quality feed grade crops. As well, more work on pasturing hogs and poultry can help determine optimal levels on pasture.
- At a systems level, there is a need to rationalize selection of animals. At present, much of the focus of organic meat production is on cattle, partly because of the pasture related implications, 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, so there's an energy logic to favouring hogs over cattle which have much higher basal and reproductive metabolism. Dairy animals do, however, also have a favourable conversion ratio for milk. Pigs also tolerate a wide range of environments. As discussed above, however, how to best take advantage of these biological realities has yet to be fully explored in organic hog systems. Chicken and eggs are next on the energy conversion scale, suggesting they warrant more attention in landscape level planning for energy efficiency. Ultimately, fish are much more efficient feed converters than farm livestock, so it makes sense for the organic sector to devote more attention to ecological herbivorous and omnivorous fish systems in the longer term.
- Reducing feed losses will improve overall system efficiency.

Reconsidering the PSL over time

- Some, including Smil, are arguing that feeding 9-10 billion will not be possible without the use of synthetic macronutrients[67]. Although regions such as Ontario appear to be relatively self-sufficient in crop nutrients from manure and biological sources alone[68], most parts of the world don't have such animal stocking densities. In the Smil interpretation, if synthetic macronutrients are not used, then more land has to be brought into production or animals stocked at higher rates to increase manure production, neither of which is desirable. If this proves to be

> accurate, then the organic sector must think through how large a percentage of global production it can become before the Permitted Substances Lists might have to be altered to reflect such realities.

b.2 Consumption

The organic sector has generally focussed its consumption concerns on the purchase of organic food, with some sub-sectors concerned about issues of locality, nutrition, and eating low on the food chain. From an energy perspective, these considerations have to be brought to the fore over the medium to long term.

Dietary choices

Energetically, eating closer to the sun definitely helps with overall system efficiency, in that energy is always lost the more consumption stages it passes through. When humans consume products from animals fed crops humans can consume, or on land that can be devoted to human food crops, energy and land use efficiency go down.   This is to some degree mitigated when animals are fed plant matter that humans can not digest (including crop residues), on land better suited to pasture than field and horticultural crops[69]. Given current consumption trends showing the average Canadian eating too much protein, particularly animal protein and under-consuming whole grains, fruits and vegetables[70], there is a movement in nutrition circles to encourage dietary shifts that could ultimately favour the energetic efficiency of organic production. And since organic production of animal products lags behind crop production, supporting such consumption shifts would not unduly penalize animal producers in the organic sector.

Reducing highly processed, high calorie foods (commonly referred to as junk food) from the diet will also improve energy efficiency[71]. The average Canadian consumes more calories than is generally required for good health[72], and junk food requires significant energy for processing, especially in relation to its nutritional value. Relative to conventional processing, organic standards restrict the kinds of processing techniques and aids that can be employed. It is sensible, therefore, for the organic sector to discourage the development and marketing of highly processed, high calorie organic junk food.

Some other consumption changes are more favourable to organic production. For example, increases in pulse consumption, greater acceptance of the taste of grass-fed animals, shifts among animal product selections towards sheep, cow and goat milk products and eggs are all energetically more desirable. Among meats, pork and chicken are likely favoured over beef given the greater efficiency of these animals at producing consumable products, although much depends on how much pasture land is available. Greater focus on pasture and residues as feed sources will also reduce corn and soybean production for animal feed. Oats and barley are important rotational crops in organic systems and are generally underconsumed relative to their nutritional value[73]. Shifting from animal feed to human varieties would be desirable as animal production consumption was scaled back.

Packaging reduction

Packaging is responsible for about 7% of food system energy in the US[74]. Assuming similar Canadian percentages, the organic sector could work with the packaging sector to "lighten" packaging or reduce use of the most energy intensive forms. Aluminum cans, for example, require 1600 kcal of energy to produce, with another 500 kcal to make a typical soda, all to deliver 0-1kcal of consumable energy[75].

Distribution – food miles

Although differences in GHG emissions are significant when comparing organic and conventional production, the larger contributors to greenhouse gas emissions are certain modes of global food transport. Pretty et al. (2005) concluded in a study of global vs. local conventional and organic meals that although organic vs. conventional production produced 2-3 fold emission reductions, this paled by an order of magnitude to the savings when eliminating air freighted long distance imports[76]. The kg $C0_2$ equivalent emissions / tonne*km are dramatically higher for air and truck than for ship and rail[77]. The size of the truck also has a significant impact on emissions, with those from small 3.5 tonne vans very similar to air freight[78].

How might the organic sector respond? At least one Swiss certifier has prohibited transport by air[79], and the UK Soil Association seriously considered such an action before relenting because of the negative implications for farmers in the global south[80]. Sophisticated strategies will be required to build local supply chains that replace air freighted goods but do not rely on small van deliveries, if significant emissions are to be generated. A related challenge will be assuring energy efficient local season extension with greenhouse production and storage. There are very energy efficient greenhouse technologies available, both simple and elaborate, but are organic producers using them? Extensive storage can add 8-16% of energy use[81], and how might that energy use contrast with that of imported goods? Pimentel et al. (2008) have argued, in contrasting California lettuce exported to New York, with locally produced cabbage, that the production, irrigation and transport energy costs of the lettuce so exceed the production and storage costs of local produce, that such scenarios should generally be positive in energy terms[82].

Part IV - integrating energy crops and on-farm energy production

To be consistent with organic farming practices, energy crop and on-farm energy production should be rooted in agroecological principles. In theory, the more energy and nutrient self-reliant the farm is, the better. Consistent with organic certification standards requiring whole farm conversion[83], for most farms, energy production should be a coherent and integrated complement to food production. The rationale for such an approach is augmented by evidence that other energy efficiency and generation strategies, such as solar collectors, offer much larger opportunities, largely because of the energy inefficiencies associated with passing solar energy through plants and animals[84].

In this section, energy production integrated with food growing is explored, including energy crops, and crop and animal waste. Other energy related issues, such as building, motor and process energy efficiency, geothermal, windmill, solar and small dam hydro, are not discussed.

It would appear that the ideal scenario for integrating energy crops into an organic farming operation has the following characteristics. These characteristics are derived from agroecological theory (Altieri, 1995) and Robertson et al (2008).

Characteristic …. the energy crop or a source crop for biomass waste:	**Rationale**
Has a high energy output/input ratio	Given criticisms of ethanol fuels, energy crops / biomass waste must be highly energy efficient
Does not occupy land well suited for food crop production or does not result in residue removal so that soil health is compromised for subsequent food crops; unless it is an annual plant that serves an important function in the food crop rotation	Organic crop prices are generally significantly higher than energy crop prices, so this is economically sensible. Also addresses global concerns about inappropriate land use reallocation to energy crops
Provides good soil cover for most of the year; perennials that do not regularly require renovation favoured over annuals	Since energy crops will likely occupy less productive lands, protection from erosion is critical
Returns significant organic matter to the soil, either in residue returned, or root mass	To ensure health of marginal soils
Does not require significant fertilization	Crops with low fertility requirements preferred to accommodate marginal soils and low management requirements and costs
Does not have many pests and is not an alternate host for food crops; competes well with weeds	Reduces management time and expenses, creates better compatibility with other crop systems on farm
Does not result in significant exports of nutrients off farm, or lends itself to on-farm processing or off-farm processing that can lead readily to recycling of processing and / or combustion residues	Export of P, K and some micronutrients can be a problem in some organic operations, so minimizing nutrient export helps close the nutrient cycle
Enhances biodiversity and is not invasive	Since energy crops may occupy the “marginal” spaces on the farm, biodiversity enhancement is a priority. Globally, there is a need for agriculture to maximize diversity
Requires minimal attention from farmers so that energy crop operations do not compete with food crop operations	Since food crops are the priority, their management should not be compromised
Does not require specialized equipment for	Expenses are minimized if operations can

planting and harvest	be handled with existing equipment
Lends itself to more localized distribution chains, with low processing and distribution costs	Transport should be minimized so that energy is not lost in distribution. This requires a decentralized approach to processing and distribution
Is remunerative, but not so much so that it represents the highest profit centre on the farm	Price signals should not be so high as to encourage expansion of acres onto lands designated for food crops

A key system level consideration is what the energy crops replace as a farmer transitions into such production. Ideally, land that was degraded[85] or at least marginal for annual food or feed crops or poorly managed pasture, and could have been creating negative environmental impacts as a result, is converted to an energy crop that meets the above criteria. Less desirable is conversion of well managed pasture to energy crops. Least desirable is conversion of natural habitats to energy crop production, especially annual plants because the loss of soil carbon significantly reduces or eliminates the benefits of generating alternative fuels[86]. The possible exception would be no-till row crop systems where total SOM is maintained post-conversion in the upper 30 cm, although the quality of the SOM may shift, thereby causing some aggregate breakdown and affecting the permanence of the pool[87].

Of course, the ideal scenario is rarely achieved, and farmers often have to make decisions for which some criteria will be compromised. However, there appears to be a very limited case for organic farms to produce feedstock for ethanol or biodiesel in the near term, for reasons of both farm finances and broader organic system requirements. The case against conventional grain-based ethanol is strong[88] and even stronger in an organic farming scenario, since organic farmers generally reduce corn area post – conversion because of its demands on soil resources. Canola-based biodiesel is not an option since organic canola production has largely been eliminated by GE contamination, and what organic canola is grown commands such a significant premium that it makes no sense to produce it for energy. Soybean-based biodiesel would also not appear to be a viable option, as prices for human-market soybeans are generally high and there is a significant shortage of affordable feed grade organic soybeans. On-farm biodiesel production, using simple processing technologies[89], may be an option if the crop is poor. Cellulosic ethanol is a better fit with the criteria outlined above, except that the capital costs are significant, leading to centralized production facilities, and the technology has yet to be fully commercially proven. In the longer term, however, once the technology is better developed and more widely available, cellulosic ethanol from harvested set aside grasslands could be one of the more energy efficient biofuel scenarios[90]. However, there remains some dispute about the energy efficiency of many cellulosic ethanol processes[91].

According to Smith et al[92], deeply rooted perennials are usually better than using crop residue for feedstock. On mixed operations, straw serves useful functions in bedding materials and compost making, and eventually is returned to the soil, sometimes important for maintaining K balances[93]. Even in stockless systems, it is not obvious that much crop biomass can be diverted to energy production, unless the SOM levels on the farm have reached an optimal steady state that only requires minimal OM additions to maintain[94].

Some of the energy crop and biomass systems that appear to best meet these criteria include:

1. Mixtures of C4, C3 and leguminous grasses and forbs[95]

2. Switchgrass[96] (including overwintering for spring harvest)

3. Short rotation forestry – willow or poplar[97] or alder[98]

In the near term, using these three feedstocks for solid rather than liquid fuels appears to be a more viable option because of energy conversion efficiencies, GHG reductions, and the technology required for liquid biofuel production[99]. Ideally, ash from combustion of solid biofuels is returned to farms[100].

Although some of these systems may perform better on more valuable land, or with higher levels of fertilization (i.e., the additions of manure and other N sources would increase yields sufficiently to offset energy expended during biomass application), allocation of higher quality land and biological N to energy crops may not make sense within a whole organic farm context given competing uses for land and nutrients. Alder has an advantage in this regard because of its relationship with N fixing bacteria. If the N source for energy crops was not one to be applied to organic food crops, e.g., sewage sludge, then there is perhaps an argument for more fertilization (for more on this, see section V).

A Danish study of national conversion to organic farming found that allocation of 5% of farm land to short rotation forests as a 20-year macrocrop rotation could offset as heat and power 30-58% of the energy inputs into organic farming, depending on the production scenario. However, their use for heat and power could not address farm liquid fuel requirements[101].

Another strategy for home and farm use is to produce biogas using simple on-farm digesters with on-farm biomass or to establish cooperative regional biogas plants that local organic farms feed into. There are numerous design proposals for on-farm biogas generation with by-products returned to the soil[102]. The key concept is to make the biogas operation an efficiency addendum to the farm fertility strategy. Given a preference in organic farming for solid manure systems, rather than slurry, the range of truly efficient biogas operations may be limited if animal wastes are the substrate.

In cases where organic farmers have excess plant-based substrates for biogas generation (e.g., in several parts of Europe where frequently stocking rates are low or systems are stockless and production of grass-clover mixtures is significant, exceeding feeding requirements), then biogas generation is potentially more feasible[103]. However, such conditions are less likely to exist among North American organic operations in the short term.

Ultimately, the economic value of biogas may be determined by buy-back prices from electrical utilities, and whether the biogas residue creates an improved and acceptable fertility source for organic crops. A German study concluded, “new capital investments are or could be profitable, if the biogas plants are imbedded into reasonable integrated concepts. Biogas plants have to be adapted to the flow of materials on the farms and their business environment. The main factors of success are high waste heat usage, internal benefits like positive effects on crop production. These are created by the improvement of liquid manure and the use of cost effective substrates such as residuals or by-products of crop production. Currently exclusive production of energy crops is uneconomic, because of the high production costs of organic substrates. Therefore the acquisition of conventional substrates, especially maize, is feasible from an economic point of view. However, this depends on future developments of substrate prices. Also the growing demand for conventional substrates is very critically observed by organic farming associations.”[104]

Part V - is the use of sewage sludge a viable fertility and energy efficiency strategy or organic farms?

Although in ecological theory there’s a sound rationale for using properly processed human manure (humanure) and urine on plants, there exists a huge gap between the potential purity of individual household humanure (assuming the family is healthy and not requiring significant medication) and the end products arising from current residential human waste collection and treatment systems. The failure to separate residential and industrial sewage and the nature of the sewage treatment processes explain, in part, the prohibition on sewage sludge use in organic standards. The prohibitions against sewage sludge may become stronger as more is uncovered about how plants take up various substances excreted from animals (and possibly humans), such as antibiotics[105] . A suite of environmental chemicals found in sewage sludge may also have negative impacts on farm animals, particularly pregnant ones[106]. Under current rules and existing realities, it might only be in some newly designed eco-communities where properly composted human waste[107], or source separated urine from people in good health[108], would be “clean” enough to use on organic farms.

More productive use of human waste, including use of technologies for nutrient extraction rather than whole production application, is a significant opportunity to improve the overall energy efficiencies of agriculture, consistent with the earlier discussion of better utilization of underused off-farm organic material.

Is there a possible role for sewage sludge on energy crops in organic farm operations? As discussed above, a modest level of fertilization with materials that don’t compete with food crop requirements, could provide some yield and efficiency advantages, potentially compensating for nutrient and organic matter losses if ash from energy crop combustion can not effectively be returned to contributing farms.

In some European countries, including Denmark, where there has been some success reducing heavy metal and persistent organic compounds in sewage sledge, a reconsideration of the prohibition on sewage sludge has been proposed for energy crops. With careful management and modest application rates, there is some evidence that use of such cleaner sludge may not unduly increase contaminants in short-rotation forestry soils[109]. However, much would likely need to be done to improve the quality of Canadian sludge before such a proposal could be entertained.

Summary of further work

To improve energy efficiency and GHG mitigation potential of organic systems, priority areas for future research include:

- Yields in monogastric organic animal production systems and horticultural crops
- Improving the design, nutrient cycling, and photosynthetic efficiency of organic crop rotation and tillage systems
- Better matching of animal types, stocking rates and agronomic functions to nutrient and energy flow dynamics of organic operations
- Energy efficiency of composting systems
- Optimizing root / microbe interactions
- Mechanisms for landscape level planning of organic production to match biophysical and moisture resources of each region
- Soil restoration using organic farming
- Reducing and recycling food waste in organic supply chains
- Linking the organic movement to structural efforts to reduce obesogenic environments
- Linking dietary choices with the development of the organic sector, including reducing animal product and processed food consumption
- Reducing reliance on long distance truck and air freight for organic food distribution
- Addressing looming labour challenges in organic agriculture (and the Canadian food system more generally)
- Studies of widespread adoption of organic farming systems and their national GHG mitigation implications
- Improving the agronomic performance of targeted energy crops

Endnotes

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[1] Note that his review does not include issues around organic aquaculture production. The analysis assumes that no significant changes to organic standards in the near to medium term, including no dramatic changes to Permitted Substances Lists (PSLs) and maintaining requirements for whole farm conversion.

[2] Gomiero, T. et al. 2008. Energy and environmental issues in organic and conventional agriculture. **Critical Reviews in Plant Sciences** 27(4):239-254.

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[20] A review of Agriculture and Agri-food Canada documents related to global warming reveals these limitations.

[21] 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.

[22] For a sampling of reviews, see Arden-Clarke, C. and Hodges, R.D. 1987. The environmental effects of conventional and organic/biological farming systems. I: soil erosion with special reference to Britain. **Biological Agriculture and Horticulture** 4:309-357; Arden-Clarke, C. and Hodges, R.D. 1988. The environmental effects of conventional and organic/biological farming systems. II: soil ecology, soil fertility and nutrient cycles. **Biological Agriculture and Horticulture** 5:223-287; Arden-Clarke, C. 1988. The environmental effects of conventional and organic/biological farming systems. IV: farming system impacts on wildlife and habitat. Research Report RR-17. Political Ecology Research Group, Oxford, UK; de Vries, G.J.H. et al. 1998. **Ecological Sustainability of Agriculture and Horticulture - A Comparison of 'organic' and 'Milieukeur'**. Centre for Agriculture and Environment, Utrecht, The Netherlands; Haas, G. et al. 2001. Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment. **Agriculture, Ecosystems & Environment** 83: 43-53; Pretty, J.N et al. 2000. An assessment of the external costs of UK agriculture. **Agricultural Systems** 65:113-136.; Pretty, J.N. and Ball, A. 2001. **Agricultural Influences on Carbon Emissions and Sequestration: a Review of Evidence and the Emerging Trading Options**. Centre for Environment and Society and Department of Biological Sciences, Occasional Paper 2001-03. University of Essex, UK

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