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TITLE

ENVIRONMENTAL IMPACTS OF ORGANIC AGRICULTURE: A CANADIAN PERSPECTIVE

ABSTRACT

Canada, in 2009, will enact a regulatory regime to oversee certified organic agricultural productions systems, based on a management standard. The overreaching goal of that standard is to develop farm enterprises that are 'sustainable and harmonious with the environment'. However, empirical evidence to shed light on claims of environmental benefits from organic agriculture is particularly scarce in Canada and North America generally, and has not been comprehensively summarized. This review examines the literature of Canadian and US studies which relate to environmental impacts of organic agriculture within the selected indicators of (i) soil organic matter storage and soil quality/soil health (ii) plant and wildlife biodiversity (iii) energy use (iv) nutrient loading and off-farm nutrient losses, and (v) climate change and greenhouse gas emissions. The empirical evidence presented suggests organic farming system attributes regarding cropping, floral, and habitat diversity; nutrient intensity; soil management; and energy and pesticide use etc. are sufficiently distinct as to impart potentially important environmental benefits across the indicator categories examined. More research is needed to validate these results, for the benefit of producers, consumers and policy makers as they decide the relative importance and contribution of organic farming systems to the Canadian food marketplace and agrifood sector.

KEY WORDS

Organic agriculture, farming system, soil, biodiversity, energy, greenhouse gases

In December of 2008, Canada will enact federal regulations that enforce a new Canada Organic Regime. This regulatory system governs organic agriculture and domestic and international trade in organic products and references a new national standard for Canadian certified organic production systems (CGSB 2006). The overreaching goal of the standard is to develop farm enterprises that are 'sustainable and harmonious with the environment' and the management framework of the national standard is built around seven more specific general principles. Of these principles, five refer to environmental and ecological benefits of organic farm management, the remaining principles being related to (i) meeting the behavioural needs, and maintaining the health, of livestock, and (ii) ensuring organic product integrity. The environmental and ecological management principles specifically are to:

1. Protect the environment, minimize soil degradation and erosion, decrease pollution, optimize biological activity and 'health'.
2. Maintain soil fertility by optimizing conditions for biological activity within the soil
3. Maintain biological diversity within the system
4. Recycle materials and resources to the greatest extent possible within the enterprise
5. Rely on renewable resources in locally organic food systems

Within a new federal/provincial Agricultural Policy Framework agreement ('Growing Forward') expected to be finalized in 2008, Canadian agricultural producers may receive payments, for the first time, for environmental stewardship and services, similar to schemes employed in Europe. Canadian organic farmers may be well placed to benefit from such programs, to the degree to which claims of improved environmental management, encoded within new national standards, can be validated.

McRae et al. (2007) argue that if the true costs, externalized to the environment, of food production, were internalized, organic systems would command a greater position in the food marketplace and agrifood sector. The authors suggest that, when combined with the potential social and financial benefits derived from organic farming, for which there is increasing evidence, these systems could potentially solve broad multiple policy goals for Canadian agriculture. Dorais (2007) in a recent review of the state of the industry of one of the fastest growing sectors, organic vegetable production, notes that while organic farming aims at profitability with little or minimal impact on the environment, results are ambiguous as to whether this is achieved. Empirical evidence to shed light on claims of environmental benefits from organic agriculture is particularly scarce in N. America, and the research evidence that does exist has not been comprehensively summarized. This paper attempts to address this gap.

In N. America, consumer perception of the benefits of organic are focused primarily on the perceive benefits to health, rather than perceived broader public good benefits (environment, climate change) or improved animal welfare. In a 2005 AC Neilsen global online survey of 21,100 respondents on the topic of ‘Functional Foods and Organics’ the N. American consumer lagged the rest of the world, and the EU in particular, in the distribution of respondents citing diverse reasons for purchasing organic food (ACNeilsen 2005). Most N. American consumers (78%) purchased organic foods as they perceived these products to be a healthier choice for themselves or their children. Only 11% cited environmental benefits and 2% cited improved animal welfare as their reasons for purchasing organic foods. In contrast, nearly a fifth (19%) of European consumers regarded environmental benefits as their main reason for supporting organic farming systems, while perceived improved animal welfare was cited by 12%, and 57% for perceived health benefits. Globally, environmental and animal welfare response categories averaged 15% and 7% of respondents, respectively. While there is growing evidence that organic foods are a healthier option (Winter and Davis 2006), as noted above organic certification and production standards in Canada and worldwide are predicated on promoting the broad benefits of the farming system itself, rather than a focus on promoting the specific benefits to the end user of agricultural products of these systems.

Throughout much of Europe organic producers have received for decades direct government payments for environmental stewardship services to society (protection of water, biodiversity etc.) and these agri-environmental schemes are expected to be expanded further (Feehan et al. 2005; Zander et al. 2008). As a result there has been a longer and more extensive program of research in Europe dedicated to examining organic production systems and informing the debate regarding their merits and deservedness, or not, of government support (Arden-Clarke and Hodges, 1987; Kirchmann and Thorvaldsson 2000; Zander et al. 2008). For example, energy use has been shown to be lower in organic agriculture both per hectare and per unit crop or livestock product (Dalgaard et al. 2001). Smith (2004) proposed adoption of organic farming as one of a suite of practices to improve soil conservation and soil organic carbon (SOC) sequestration. Mader et al. (2002) found organic systems promoted shifts in soil microbial functional diversity, with benefits in resource (carbon) utilization efficiency. More recently, however, Kirchmann et al. (2007) reporting on results of a long-term (18yr) comparison of organic and conventional cropping systems in Sweden, found that while organic matter levels were depleted less under the organic regime, agronomic efficiency of nutrient (N and P) use and yields were lower with organic management compared to conventional management. In a recent special issue of the journal Renewable Agriculture and Food Systems devoted to examining the contribution of organic agriculture to sustainable agriculture systems all of the papers were European (Entz. et al. 2008). In an international conference on Organic Agriculture and Climate Change held in France in April, 2008, less than 5% of 45 total presentations were from studies conducted outside of Europe.

The objectives of this study are to review the literature of Canadian and N. American studies conducted to date which relate to the broad environmental/ecological impacts of organic agriculture. It is not meant to be an exhaustive study, but include key recent findings across various indicators from among those few studies conducted to date in each category. These selected indicator categories include (i) *Soil organic matter storage and soil quality/soil health (ii) Plant and wildlife biodiversity (iii) Energy Use (iv) Nutrient loading and risks of off-farm nutrient losses, and (v) Climate change/Greenhouse gas emissions.* It is hoped the paper will provoke further debate, spur further inquiry and research, and contribute to the discussion of the potential role of organic agriculture in solving multiple policy goals for Canadian agriculture.

DISCUSSION

Soil Organic Matter Storage and Soil Quality / Soil Health

Soil organic matter is a key attribute of soil quality. Soil organic C (SOC) levels in agricultural soils is a function of the influence of a given management systems on the net effect of the two processes of C deposition from crop residues and organic amendments versus C losses from soil respiration and SOC decay (Janzen 2006). In Canadian agricultural systems generally, gains in SOC over the past few decades have been attributed to a reduction in the use of summerfallow, and in particular to the adoption of no-till and minimum tillage practices (Smith et al. 1997). Within this context, organic farming systems are criticized for their continued reliance on relatively intensive mechanical tillage for incorporation of green manures and mechanical weed control. Few studies, however, have gauged, in a comprehensive manner, the net effects of organic management systems on SOC. In a US corn-soybean cropping systems study, it was deduced from C isotope ($\delta^{13}C$) analyses that qualitative differences in crop residues in the organic system, which included a vetch green manure, contributed to SOC gain (Drinkwater et al. 1998). No-till practices were not used in the conventional corn production system in that study, however. 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 postplanting 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 was 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. 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.

Innovative approaches to management of green manures, that reduce reliance on tillage, are increasingly being explored in organic systems. Hepperly et al. (2008) reports 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, such as no-till hairy vetch cover crop system for tomato production (Sainju et al. 2000) and are reviewed by Dorais (2007).

The influence of livestock systems and 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, as practiced by organic farmers can be a cost effective option that's promotes substantial SOC gains on the extensive acreage of, often degraded, permanent grasslands in Canada (Franzlubbers et al. 2000; Lynch et al. 2003; Lynch et al. 2005).

Enhanced soil organic matter storage contributes also to yield stability and production system resilience. Mallory and Porter (2007), reporting on thirteen years of data from the Maine Potato Ecosystem Study, found that management systems that improved soil quality, through application of compost and green manures, enhanced potato yield stability or year to year variation in yields. In particular, yields of non-irrigated potatoes grown in 2-year rotations in the amended system were much less influenced by adverse conditions, particularly poor rainfall. Pimentel et al. (2005) similarly found that the enhanced soil organic matter maintained by organic management conserved soil moisture and water resources, factors that promoted higher corn yields in five dry years in a ten year comparative farming systems trial at the Rodale Institute Farming Systems Trial in Kutztown, PA.

Soil health and biological properties appear to benefit also from the unique characteristics of organic production regimes. Organic potato farms in Atlantic Canada utilize extended (5-year) rotations including legume cover crops compared with much more frequent cropping of potatoes in conventional production systems (Lynch et al. 2008a; Angers et al. 1999). Recent studies suggest these rotations confer marked benefits to soil health including micro- and macrofauna. In a study conducted on four farm sites over two years, earthworm abundance and biomass, and soil microbial biomass appeared to particularly benefit from these extended rotations, recovering from marked reductions during potato cropping to levels found in adjacent permanent pastures only after three to four years (comprised of one year of grain followed by forages) (Nelson 2008). In a long-term (14 year) comparative cropping systems study at the University of Manitoba, organic crop management was found to promote mycorrhizal colonization and increase mycorrhizal spore populations (Welsh et al. 2006).

Plant and Wildlife Biodiversity

Is their Canadian or N. American evidence that the increased spatial and temporal diversity of organic cropping systems, and avoidance of the use of herbicides, increases floral and wildlife diversity? In an era of increasing agricultural intensification and specialization, can organic farming significantly contribute to Canada's commitment to maintenance of biodiversity. In a recent study in Ontario, of crop fields and woody hedgerows (boundary and centre) of 16 conventional and 14 organic sites, clear differences were found in species richness and composition between the organic and conventional study sites. Fields and woody hedgerows situated in organic sites consistently harboured more native and exotic plant species than those in conventional systems. Numerous species were only found in organic hedgerows and included several long-lived herbaceous forest species (Boutin et al. 2008).

Intensive agriculture, combining increasing specialization in intensive arable cropping, expanded herbicide use and reduced need for rotations, has strongly affected the composition, heterogeneity and interspersion of wildlife habitat in agricultural landscapes in North America. Farm fields have become characterized by low within-field and between field variability, while field margins and other-non crop habitats have been reduced or eliminated. Strong evidence exists that these changes can have substantial adverse effects on wildlife, including beneficial insects and birds (Freemark and Boutin 1995), and the increased spatial and temporal variability of crops and non-crop plant species in organic systems may be of particular benefit in this regard. Freemark and Kirk (2001) counted birds during the 1990 breeding season on 72 field sites in southern Ontario, across 10 organic and conventional farms. To enable effects of agricultural practices to be detected, sites were matched for crop and non-crop habitat characteristics, including crop type, adjacent non-crop habitat, and when possible, field size and shape. While species composition was similar, of sixty eight bird species recorded, the species richness, abundance and frequency of occurrence was significantly higher on the organic than the conventional sites. Among sites local habitat and agricultural practices each contributed roughly equally to the variation in bird species. Differences found between farm types were considered most likely due to reduced availability of nesting sites and food supply due to lower plant species richness, cover, seed availability, and soil invertebrates on conventional farms.

These results suggesting enhanced floral and wildlife diversity on organic farms are consistent with a growing body of literature, primarily European in origin (see review by Hole et al. 2005), that has indicated that species abundance and richness, across a wide range of taxa (including arable flora, birds, mammals and invertebrates) benefits from organic management. Many of these benefits and relationships are undoubtedly synergistic. In Germany, Gabriel and Tscharntke (2007) for example, found insect pollinators and insect pollinated plant species benefited disproportionately from organic farming. Maintenance of habitat for native pollinators, may have important practical benefits also, in a period when colony collapse disorder and other challenges are impacting on pollinators traditionally relied upon by agriculture. While such results are encouraging, much more needs to be done to determine whether these trends are true of all organic farming systems in Canada, and improve our understanding of the mechanisms at work at the field and farm scale.

Energy Use

What do we know of the comparative net energy balance of organic management systems typically found in Canada or the United States?. A 12-year Manitoba study 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 with organic than 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. Pimentel et al. (2005) examined the comparative average energy inputs (in millions of kilocalories ha^{-1} yr^{-1}) for corn and soybeans grown under three cropping systems; namely (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. Reganold et al. 2001, in a study of organic vs. conventional apple production in Washington State found the organic system allowed a 9% reduction in energy inputs and was 7% more efficient in energy use. Organic systems in N. America as elsewhere, despite the stated principal to rely on renewable resources in locally organic food systems and reduce the dependence on fossil fuels, have largely unexplored the potential for energy self reliance via on-farm bio-energy production. The use of oilseeds or a component of grass-clover leys for biogas production on organic farms are suggested by Halberg et al. (2008).

Nutrient Loading and Risks of Off-Farm Nutrient Losses

The increase in agricultural intensification over the past forty years has greatly increased the risk and incidence of contamination of surface and ground waters by nutrients and pesticides, and this is true in Canada (CCME 2002). At the same time, it is well established, that the off-farm costs of mitigating soil and water degradation far exceed the costs of appropriate soil conservation and nutrient management practices on-farm (McRae et al. 2007).

A recent study of fifteen organic dairy farms in Ontario, Canada found that farm nutrient (NPK) loading (imports-exports), and risk of off-farm losses to air and water, is greatly reduced under commercial organic dairy production compared with more intensive confinement-based livestock systems in eastern N. America (Roberts et al. 2008). Indeed, low levels of labile soil phosphorus (measured using standard soil tests indices) as found on these dairy farms appears to be common to most organic production systems in Canada (Martin et al. 2007).

In eastern Canada in particular, an increasing acreage of agricultural soils over the past 20 years have been classified as at high risk of being a source of nitrate N losses to water (de Jong et al. 2007). In Prince Edward Island (PEI), losses of nitrates to groundwater is currently a major concern, with a provincial commission formed in 2007 and tasked with finding solutions to this problem. In humid region Atlantic Canada, most leaching losses of nitrates from agricultural soil occur between seasons. Studies on commercial organic potato farms in PEI and New Brunswick have found these systems to be moderate with respect to labile N dynamics and risk of N losses. Much lower residual soil nitrates (RSN) (<25 kg NO_3-N ha^{-1}) in the soil following potato harvest were found than for more intensive conventional potato systems in the region (Lynch et al. 2008a; de Jong et al. 2008). In these production systems, potato plant N uptake following clover or alfalfa legume plowdown was moderate at 112 kg N ha^{-1} but provided for relatively high tuber yields (~30 Mg ha^{-1}).

In addition to providing N for the following cash crop following their incorporation, legumes in organic crop systems also act as an ‘N buffer’ during their growth, reducing the risks of large excesses or deficits of N, and by accommodating lower application rates of organic amendments, reduce soil P and K accumulation (Lynch et al. 2004). Kramer et al. (2006) used ion exchange resin bags placed below the root zone to determine annual nitrate leaching from conventional and organically managed orchard systems in Washington State, and found 4.4 to 5.6 times greater nitrate leaching in conventional compared to organic plots.

Management of green manures to avoid excessive N release is a continuing challenge for organic systems. Pimentel et al. (2005), after a 12-year period of monitoring used intact lysimeters to gauge cropping system impact on water quality, found sporadic increases in nitrate leached under corn to follow incorporation of a hairy vetch green manure. This was particularly the case when drought conditions reduced corn growth and N uptake. However, it is notable that averaged over all 12 years of monitoring, differences in annual nitrate leached per year were not significant, as found also by the Kirchmann et al. (2007) cropping systems study in Sweden.

While these general results on reduced nutrient intensity and levels of reactive N and P within organic cropping and livestock systems are encouraging, with the exceptions of the US studies cited (Drinkwater et al. 1998; Kramer et al. 2006) very little research effort in N. America has been dedicated to directly examining the impact of organic farming systems on water quality. In order to help address this gap in information, a new replicated, tile-drained and instrumented field research facility has been recently installed at the Nova Scotia Agricultural College (NSAC), in Truro, Nova Scotia to broadly gauge the impact of organic management systems on water (and soil and air) quality, and specifically to assess potential benefits of novel technologies, such as crop rollers compared to standard mechanical tillage for green manure management, and innovative tests of soil N availability.

Climate Change / Greenhouse Gas Emissions

There is a scarcity of studies in Canada and N. America generally which have examined the impact of rotations characteristic of organic management on temporal variability of N_2O emissions and overall trace gas budget, and how the synchrony of N supply and crop demand compares between inorganic N fertilized and organic N source (legume, compost) regimes and their relationship with N_2O emissions. In these soils, the reliance on legume N_2 from biological nitrogen fixation, and relatively high quantities of stable organic matter may regulate the availability of soil nitrogen and carbon needed for release of greenhouse gases (GHG) (CO_2, N_2O and CH_4).

Robertson et al. (2000), compared the net global warming potential (GWP) of conventional tillage, no-till, low input and organic management of a corn-soybean-wheat system in the Midwest USA over eight years. 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 $year^1$) 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).

In an intriguing study in a perennial orchard system in Washington State, Kramer et al. (2006) found that after nine years the organically managed soil exhibited not only greater soil organic matter and microbial activity, but also 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. Shifts in soil microbial community composition and activity, detected by PLFA and enzyme assays were considered to explain this shift in denitrifier community efficiency under organic management and higher SOC conditions. As there was reduced nitrate leaching under the organic system, the authors concluded that organic system fosters an active and efficient denitrifier community that performs a ‘valuable ecosystem service’ by removing excess nitrate from the system and converting it to benign N_2. Shifts in microbial diversity and efficiency (of carbon use) under long term organic management have been shown elsewhere, most notably in the Swiss DOK trial and reported by Mader et al. (2002).

Very few studies internationally have examined nitrous oxide emissions from unfertilized pure forage legume stands, a common feature on organic livestock and arable crop farms (Rochette and Janzen 2005). Lynch et al. (2008b) recently presented interim results from an ongoing studies in Atlantic Canada (NSAC, Truro, Nova Scotia) examining the effect of crop (red clover, timothy or potato), timing of forage tillage (spring/fall), and potato fertility regime (preceding crop with or without fertilizer N addition) on N_2O emissions. The clover-based and unfertilized forage and potato management system closely mimics the management regime of commercial organic potato farms in Atlantic Canada. Interim results (data not shown) indicate the forage and potato crops relying on organic N sources, including for forages biological N_2 fixation, emitted less N_2O (4.4 kg N_2O-N ha^{-1}) than those supplemented with inorganic fertilizer (up to 11.6 kg N_2O-N ha^{-1}), while maintaining acceptable yields of forage and potatoes. These latter results concur closely with the European study of Petersen et al. (2006) who found N_2O emissions were lower from various organic than conventional crop rotations (some including potatoes), ranging from (~4.0 kg N_2O-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 comparison to the EU (Olesen et al. 2006; Halberg et al. 2008; Kustermann et al. 2008) no N. 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 E use. There is tremendous scope similarly for expanded Canadian research on organic livestock systems and GHG emissions. Organic farming systems are highly dependent on legume N_2 from biological nitrogen fixation (Roberts et al. 2008; Lynch et al. 2008a). As N_2O emissions appear not to be not directly derived from legume N_2 fixation as previously assumed by the Intergovernment Panel on Climate Change (IPCC 1997), Rochette and Janzen (2005) and others have argued for a revised IPCC coefficient related to legume N_2 fixation. This important consideration has not as of yet featured in the methodology of farm scale modeling exercises and should be included in future efforts in this regard.

CONCLUSION

The empirical evidence to date presented here, suggests that attributes of organic farming systems, (diversity of crops, flora and associated on-farm habitat; farm nutrient intensity; emphases on rotations and soil management; reduction in energy and pesticide use etc.), across a range of production systems characteristic of those found in Canada, are sufficiently distinct as to impart potentially important environmental benefits, across the range of environmental and ecological indicator categories examined here. Much more needs to be done to validate these results, and to attempt to understand the mechanisms involved, not only for the benefit of all producers, but also consumers and policy makers as they decide in the coming years the importance and contribution of organic systems to the Canadian food marketplace and agrifood sector.

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