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Review

The Sustainability of Organic Grain Production on the Canadian Prairies—A Review

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Abstract: Demand for organically produced food products is increasing rapidly in North America, driven by a perception that organic agriculture results in fewer negative environmental impacts and yields greater benefits for human health than conventional systems. Despite the increasing interest in organic grain production on the Canadian Prairies, a number of challenges remain to be addressed to ensure its long-term sustainability. In this review, we summarize Western Canadian research into organic crop production and evaluate its agronomic, environmental, and economic sustainability.

Keywords: organic agriculture; conventional agriculture; sustainability; Canada; grain farming

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1. Introduction

Organic agriculture is described by the International Federation of Organic Agriculture Movements (IFOAM) as, “a whole system approach based upon a set of processes resulting in a sustainable ecosystem, safe food, good nutrition, animal welfare and social justice” [1]. Organic production systems operate according to standards which, among other things, aim to promote ecosystem health, while discouraging the use of many non-organic inputs, such as synthetic fertilizers, pesticides, and certain veterinary drugs. Interest in organic production and organic food products has been increasing rapidly in recent years, due to a number of factors, including concerns about environmental sustainability, human health, and rising input costs of conventional agriculture.

Globally, the market for organic food products doubled between 2002 and 2007, to more than $46 billion (USD) [2,3], with North America representing one of the fastest growing markets in the sector. Canadian sales of organic products exceeded an estimated $1 billion in 2006 [4]. In 2009, Canada enacted new federal regulations for organic production, requiring mandatory certification to a revised national standard for all products represented as organic in inter-provincial or international trade. These regulations replace a previously voluntary certification process and address issues of regulatory equivalency between major trading partners [5].

The number of certified organic farms in Canada has also been on the rise, increasing 60% between 2001 and 2006. In 2006, there were about 3,500 certified organic farms, representing 1.5% of all farms in Canada [6]. Nearly half (45%) of these farms are situated in the Prairie Provinces, with Saskatchewan accounting for about one-third of the nationwide total. Like their conventional counterparts, most (95%) organic producers on the Prairies are engaged in the production of hay or field crops, primarily wheat and barley, but also including a variety of other grains, pulses, and oilseeds [6].

Despite the steady growth in the organic sector in recent years, it remains a fledgling research area, particularly in Western Canada. Most of the information on the benefits and impacts of organic agriculture is based on research from Europe, and there has been comparatively little research focused on the contribution of organic production to sustainable agriculture in the Canadian context. While many recognize the intuitive appeal of organic agriculture as a low-input, holistic alternative to conventional production systems, serious questions remain about its long-term sustainability. In the Canadian Prairies, there is particular concern about the depletion of soil phosphorous from organic grain production [7], and the long-term impacts of tillage practices employed by organic producers [8]. Grain yields under organic management are, on average, lower than under conventional management, and it has been suggested that the yield deficit is more severe on the Canadian Prairies than some other regions [9]. Even where yields are similar, reliance on rotational strategies over synthetic fertilizers to maintain soil nutrients may place a further constraint on the overall productivity of organic cash crops [10]. Conversely, some studies have suggested that organic production on the Prairies requires less overall energy and contributes less to greenhouse gas emissions than conventional production, largely owing to its rejection of synthetic nitrogen fertilizers [11,12]. From a consumer's perspective, besides the environmental impacts, there are questions about food quality, safety and affordability.

The contribution of organic production to sustainable agriculture, then, in large part depends on how sustainability is defined and evaluated. Agriculture and Agri-Food Canada's Sustainable Development Strategy suggests that sustainable agriculture: (1) "protects the natural resource base; prevents degradation of soil, water, and air quality; and conserves biodiversity", (2) "contributes to the economic and social well-being of all Canadians", (3) "ensures a safe and high-quality supply of agricultural products", and (4) "safeguards the livelihood and well-being of agricultural and agri-food businesses, workers and their families"[13]. Many proponents of organic agriculture accept it as a system that is by definition sustainable. For example, the Rodale Institute describes organic food as food produced by "tried and true sustainable methods that are as close to nature as possible" [14]. IFOAM has integrated the concept of sustainability into its official definition as well as its four overarching principles of organic agriculture—health, ecology, fairness, and care [15]. Other advocates of sustainable agriculture have more clearly delineated differences between sustainable agriculture as a general concept and organic agriculture as a specific example of a sustainable production system; inherent in this separation is a recognition that not all organic systems are necessarily sustainable [16].

In this review, we will summarize Western Canadian research on organic grain production and evaluate the sustainability of organic grain production on the Canadian Prairies in relation to its agronomic, environmental, and socio-economic aspects.

2. Agronomic Aspects of Organic Grain Production on the Canadian Prairies

A dichotomy exists between the extensive nature of conventional grain farming (average farm size = 424 ha; [17,18]) and the more intensive nature of organic grain production on the Prairies (average farm size = 132 ha; [18]). Organic grain producers rely on many non-chemical agronomic techniques to remain viable, and agronomic issues were consistently ranked as major priorities in recent research needs surveys. In Saskatchewan, Manitoba and Alberta, three of the top four overall production concerns related to field crops, and specifically called for research into weed management, crop rotations, and managing soil fertility/soil quality [19-21]. This is not surprising in light of the reduced yields, increased weed pressure, and reliance on non-chemical approaches for weed control and soil fertility management typical on organic farms. Most Prairie producers are relative newcomers to organic production, with 50–86% of respondents reporting less than 10 years of experience in organic management. The greatest yield reductions are often experienced in the transitional and early years of organic production [22], and this is reflected in the priorities identified by these surveys. In the following section, we review the state of Canadian research into organic weed control and soil fertility management, and comment on their potential impact on the sustainability of organic grain production on the Prairies.

2.1. Weed Management

Competition from weeds is known to reduce grain yields in both conventional and organic systems, but is often a particular challenge for organic producers due to the greater weed abundance and diversity on organically managed lands [23]. Organic producers employ a variety of methods to manage weeds, including increased seeding rates, mechanical weeding, crop rotations that disrupt the growth habit of problem weeds, and selection of cultivars that are highly competitive against weeds. Canadian organic standards also permit the use of acetic acid and plant extracts (*i.e.*, pine oil) for weed control, but these may not be economical on a large scale [24]. Biological weed controls such as the fungus *Phoma macrostoma*, have shown promise against a variety of broadleaf weeds (including annual sow thistle and wild mustard) in preliminary research trials, but have not yet been released for widespread agricultural use [25].

Mechanical weeding methods, particularly pre-seeding tillage, are common on organic farms, but have been criticized as a primary method of weed control due to their disruption of soil structure, leading to increased erosion risk. The widespread adoption of zero-tillage practices on the Canadian Prairies has been considered a major advancement in the sustainability of conventional systems, due in large part to the reduced erosion risk and increased retention of soil moisture [26]. An assessment of management practices in the United Kingdom, where more long-term data on organic systems is available, concluded that conventional zero-tillage is environmentally superior to organic systems employing intensive tillage practices, based on a number of criteria [27]. A nine year study from the United States, on the other hand, found that organic management with minimum tillage could provide greater long-term benefits to soil quality than conventional zero-tillage [28]; however, the authors concede that reduced tillage under organic management may not provide satisfactory weed control. Weed populations on the Canadian Prairies have been shown to be responsive to different tillage intensities, with many biennial and perennial weeds prevalent under reduced tillage and annual weeds more strongly associated with conventional tillage systems [29]. A survey of Canadian organic and conventional farmers indicated that around 60% of organic farmers had reduced tillage practices on their farms [30]. Conventional farmers were more likely to use zero-tillage and/or direct seeding systems, while organic producers relied on other forms of conservation tillage which aim to minimize the amount of soil disturbance. In Canada, there have been few studies specifically comparing erosion risk on organic and conventional farms, but one study comparing soil samples from organic and conventional farms in the Canadian Prairies suggested that crop rotation had a much larger influence than the type of production system on erosion risk [8].

There are a number of other practices that can be used in conjunction with mechanical methods to manage weeds and reduce soil erosion risk. The use of perennial forage crops such as alfalfa, in crop rotations, has been reported to markedly reduce weeds in the following year [31]. Cover cropping (planting generally leguminous crops in lieu of fallow), underseeding (planting nurse leguminous crops with grains) and the use of green manures (plowing in cover crops) are cropping strategies of potential value for organic grain production, as they represent non-chemical methods for controlling weeds and improving soil quality [32]. Nitrogen (N) recovery from green manures is generally much higher (70–90%) than from synthetic fertilizers [32]. Fast growing leguminous species grown as cover crops and harvested as silage (or plowed under as green manure) have potential as a weed control strategy in organic systems. There is, however, little scientific literature on these strategies for organic systems on the Canadian prairies.

Wiens *et al.* [33] reported that in the wetter eastern regions of the prairies, alfalfa mulch derived from strip farming in association with wheat could suppress weeds in the wheat crop. They also reported higher N uptake with alfalfa mulch treatments than with synthetic fertilizers in the wheat and second-year oat crop, and the oat crop also had a higher grain yield. Malhi *et al.* [34] reported that organic cropping systems employing some form of fallow, or green manure partial-fallow, tend to accumulate more nitrate-N in the rooting zone than high input systems. They further suggested that fallow systems employing a green manure limited leaching because they temporarily stored available nitrate-N, while using soil water that could drive leaching, compared with fallow that excluded vegetation.

There have been a number of integrated weed management studies in south-central Alberta incorporating cover crops, underseeding and green manures [35-39]. While all of these studies included some form of chemical management in the protocol, all related their work to potential for organic systems. Sweetclover green manure used in lieu of fallow in dryland systems strongly suppressed weeds whether harvested as hay, left on the surface, or incorporated [35,39]. The authors suggest that some of the weed suppression effect of sweetclover may have been due to allelopathic compounds. Alfalfa, red clover, or Austrian winter pea were grown as spring or winter planted cover crops in dryland systems of the western Prairies [37]. Spring planted legumes exhibited limited growth, and there were some problems associated with winter kill, crop yield suppression and/or weed control, with all cover crops except alfalfa.

In general, while the theoretical benefits of cover cropping, underseeding and the use of green manures are evident, many have not been tested in the diverse growing conditions represented by organic management systems of the Canadian prairies. Anecdotally, however, our research group has collaborated for many years with a large-scale (600 ha) organic grain producer in Alberta who plows in leguminous grain mixtures every second year for weed control and nutrient management. He thus profitably sacrifices economic yield in every second year. In addition, this farmer incorporates crop fields where weeds become too prevalent prior to seed set, as a matter of course. The long term effect on soil as a result of this extensive use of tillage has not been studied.

Optimization of seeding rates for organic production may also be beneficial for yield maintenance and weed control, provided the increased input costs are not prohibitive. Increasing seeding rates has been shown to be an effective strategy for enhancing crop competitiveness in integrated weed management systems [39,40], or other reduced input systems aiming to decrease herbicide use [41]. O'Donovan *et al.* [42], found that increasing barley crop densities enhanced the effectiveness of the herbicide tralkoxydim on wild oats, allowing for reduced application rates. Increasing seeding rates in a wheat-canola rotation reduced weed biomass and the weed seedbank after four years, with no reduction in crop yield [43]. The same authors found that when the increased seeding rates were used, herbicide application at 50% of the recommended rate was often as effective as the recommended rate. In canola, cultivar selection and increasing seeding rates were major factors in reducing dockage [44]. Economic analyses of barley-field pea and wheat-canola rotations in an integrated weed management system have demonstrated such practices to be cost-effective, particularly in the case of wheat and barley where the increased seed costs are readily offset by the agronomic gains [45]. Recognition of these benefits has led many farmers to increase their seeding rate by 50% in the past five years, with many organic farmers doubling or tripling their seeding rate [46].

In organically managed wheat and barley, doubling the seeding rate enhanced weed suppression and increased grain yields by about 10% on average [47]. This effect was not cultivar specific, and the estimated net economic returns were generally positive. A farm-scale, Canada-wide trial of different seeding rates in organically managed spring wheat suggested that a 1.25x seeding rate was nearly as effective as 1.5x or 2x seeding rates for increasing grain yield [48], and would likely make the economic return even more favourable. In organically managed pulses in Saskatchewan, increasing the seeding rate substantially above the conventional recommendation led to weed biomass reductions of up to 59% and 68% for lentil and field pea, respectively [49,50]. In lentil, economic returns were positive at the highest recommended seeding rate of 375 viable seeds m^{-2} [49], while in pea, an intermediate seeding rate (200 seeds m^{-2}) provided the best compromise between weed biomass reductions, yield gains, and input costs [50].

Crop mixtures have been considered as an agronomic approach to reducing weed pressure, protecting against pests and diseases, and enhancing yield stability [51,52]. Mixtures of Park wheat and Manny barley, for example, were shown to have equal or greater yields than monoculture wheat under organic conditions, which may be partly attributed to the weed suppressive ability of Manny barley [51]. Mixtures of AC Superb and AC Intrepid (1:1 or 1:2) wheat were found to have greater stability than AC Superb alone [53]. Pridham *et al.* [52] found that mixtures of wheat did not provide a yield advantage, but helped stabilize yields in the presence of disease susceptible cultivars. Further evaluation of intercropping wheat with other cereals and several noncereal crops, however, did not demonstrate a clear benefit over monoculture wheat [54].

A number of studies have suggested it may be possible to develop more competitive wheat cultivars for organic management through breeding [23]. Conventional breeding programs have largely focused on maximizing the yield potential of grains and oilseeds, with less emphasis on selection for competitive traits, due to the widespread use of synthetic herbicides in conventional agriculture. In some cases, selection for increased yield may have resulted in the loss of certain competitive traits. For example, modern semidwarf wheat cultivars have increased grain yield at the expense of plant height, which has been associated with weed competitiveness [23]. This has led some to suggest that cultivars developed before the advent of modern, high-input agriculture may be better suited to organic production. A comparison of 63 historic and modern spring wheat cultivars under low-input conditions generally supported the trend toward higher yield in modern cultivars, coupled with a reduction in weed suppression ability [55]. In another study, 27 wheat cultivars spanning more than a century of Canadian wheat breeding were compared, and it was found that certain traits were associated with increased grain yield and/or reduced weed biomass under organic management [56]. Based on this, the authors proposed an ideotype for organic wheat that included early flowering and maturity, increased tillering capacity, and increased plant height. In another study, they further compared nine wheat cultivars differing in height, tillering capacity and maturity on organic and conventional lands with different degrees of natural and simulated weed pressure [57]. Under high weed pressure, plant height, early heading and maturity were associated with increased grain yield. Tillering capacity was important at medium and low weed pressure, but was not associated with increased grain yield under high weed pressure, suggesting that the contribution of different traits to overall competitive ability depends at least in part on the degree of weed pressure. Stability analyses indicated that older cultivars (released between 1890 and 1963) were generally more yield-stable across environments, and the cultivar Park (1963), a medium height, high tillering, early maturing cultivar, may be particularly suitable for low-input management [57]. Despite the differences in competitive traits observed under different levels of weed pressure, Reid *et al.* [58] found that heritability estimates were similar for conventionally grown wheat under weed-free *versus* simulated-weedy environments. In a direct comparison of organically managed *versus* conventionally managed wheat, however, heritability estimates were significantly different for several traits, suggesting that cultivars for organic management should be bred under organic conditions [59]. Murphy *et al.* [60] also found evidence supporting the need for breeding programs specifically tailored for organic and low-input systems. In their study of 35 different soft white winter wheat breeding lines, they found that direct selection within organic systems resulted in yields 5–31% higher than indirect selection in conventional systems [60]. Reid *et al.* (unpublished data) corroborated this apparent need for different breeding programs but did report that of the eight highest yielding (10%) wheat lines from a recombinant inbred population tested in multi-site organic trials, five were in the top 15% in multi-site conventional trials.

2.2. Managing Soil Fertility/Quality

According to the Canadian organic production standards, soil fertility should be managed using practices that "maintain or increase soil humus levels, that promote an optimum balance and supply of nutrients, and that stimulate biological activity within the soil" [61]. Effective management of soil fertility in organic systems requires an awareness of various interdependent factors, including choice of crop rotation, soil chemistry (*i.e.*, pH, salinity), soil structure, and soil microbial communities whose composition and diversity can influence nutrient cycling and availability.

On the Canadian Prairies, depletion of soil phosphorous (P) under long-term organic management appears to be a significant problem. Entz *et al.* [7] tested soil nutrient levels on several organic farms across the Prairies and found that, while nitrogen (N), sulphur (S), and potassium (K) were generally sufficient, several farms were P deficient. A broader survey of organic farms on the Canadian Prairies confirmed low phosphorous levels, particularly on farms under long-term organic management [62]. Long-term rotational studies at Scott, Saskatchewan have also reported lower soil extractable P under organic management [34,63].

Management of soil P can be a challenge because much of the total soil P occurs in forms unavailable to plants. While it is believed that mycorrhizal colonization of plant roots can enhance P availability by making recalcitrant forms of P more accessible to plants, mycorrhiza populations are particularly sensitive to management practices. For example, higher levels of active hyphae were found in clay soil treated with manure than in soils treated with inorganic fertilizers [64]. Manure processing has also been shown to have an impact on mycorrhiza, with greater colonization under composted manure compared to raw manure or inorganic fertilizer [65], and reduced colonization when using sterile *versus* unsterile manure [66]. This may be attributable to greater nutrient availability and has also been reported with inorganic phosphorous fertilizers [67].

Increased tillage intensity, common in organic systems, disrupts soil microbial communities and can also have a negative impact on mycorrhizal colonization due to the destruction of the mycelial network [68]. Such disruption may exacerbate the P depletion problem. In general, soil microbial diversity and biological fertility is best encouraged by management systems with minimal tillage, increased above-ground biodiversity (*i.e.*, diverse crop rotations or crop mixtures), and reduced synthetic inputs [68,69]. It has been suggested that a well-managed, reduced-input, zero-tillage conventional system could compete favourably against organic systems with regard to maintaining soil biological fertility [27,68].

Crop rotations may also have a major influence on P availability. For example, forage-grain rotations were shown to deplete available P more rapidly than recalcitrant forms could be mobilized [70]. Organic grain-only rotations, on the other hand, did not deplete available P as quickly, but suffered substantially reduced yields compared to both conventional grain-only and organic or conventional forage-grain rotations [70]. Conversely, Malhi *et al.* [34] did not observe a consistent effect of crop diversity on extractable P under organic management, even though P tended to be lower under organic management than under reduced or high input conventional management. Despite the more rapid P depletion under forage-grain rotations, there are a number of potential benefits of including forage crops in rotation, such as increased grain yield following the forage crop, enhanced weed suppression, nitrogen fixation, and carbon sequestration [31]. Such studies highlight the challenges of balancing rotational strategies for maintaining soil quality with overall productivity and grain yield.

There are few options available for organic management of soil phosphorous through soil amendments. Rock phosphate, while permitted by organic standards, is non-renewable and may contain unacceptable levels of heavy metals. Composted livestock manure can be applied, but sources of organic livestock manure are limited, particularly on the Prairies where organic farms are primarily engaged in crop production. The use of manure from conventional sources is permitted by Canadian organic standards provided no organic source is available and it meets certain conditions [61], but critics have voiced concerns about the presence of antibiotics and other contaminants from conventionally-raised livestock [71]. Recently, there has been renewed interest in integrated crop-livestock systems [72], which could help mitigate the P depletion issue on organically managed land while maximizing the rotational benefits of forages for both grazing and subsequent grain production [31]. In fact, it has been suggested that such an integrated approach may be key to the long-term sustainability of organic grain production on the Canadian Prairies [73].

3. Environmental Aspects of Organic Grain Production on the Canadian Prairies

The influences of organic management on soil fertility often represent the most direct and immediate environmental impact of organic agriculture, and is often a key factor in producers' decisions to adopt organic practices. Proponents of organic agriculture have argued that the environmental benefits extend further to include reductions in greenhouse gas emissions and improvements in energy use efficiency, water quality and plant and wildlife diversity [74]. To date, however, most of the long-term research into the environmental impacts of organic agriculture has been conducted in Europe and only a few studies have examined the potential impacts of organic systems on the Canadian prairies. Modeling of a hypothetical transition to organic production in Canada suggested that a total transition of Canadian canola, corn, soy and wheat production to organic management would reduce overall national energy consumption by 0.8%, global warming emissions by 0.6% and acidifying emissions by 1% [12]. Despite slightly higher fuel-related energy consumption in organic systems, the average cumulative energy demand for organic systems was estimated to be about 39% that of conventional management, mainly due to the energy-intensiveness of synthetic fertilizer and pesticide production for conventional systems. These estimates, however, are based on a number of assumptions which may not be broadly applicable to the Canadian Prairies. The study assumes yield reductions of only 5–10% under organic management, which may not be realistic, especially during and immediately following the transition to organic management [9]. Second, while the study may be useful for best-case illustrative purposes, a complete national transition from conventional to organic production is probably impractical, particularly for canola, which has already been polluted by genetically modified varieties (>95% of all varieties grown), to the extent that organic canola can no longer be grown in Canada due to outcrossing.

Field studies of wheat-pea cropping systems in Manitoba under various conventional management regimes demonstrated that nitrogen fertilizer had the greatest impact on farm energy use and greenhouse gas emissions, and was associated with reduced economic returns at application rates above 20 kg N/ha [11]. A twelve year comparison of grain-based and integrated crop rotations under organic and conventional management in Manitoba concluded that integrated rotations under organic management were the most energy efficient [75]. The authors caution, however, that soil phosphorous levels were lower in the integrated rotations than in the grain-based rotations after 12 years, and were lower under organic than conventional management. It is unclear whether any apparent near-term energy savings would remain significant once the energy costs associated with long-term phosphorous management are accounted for. In his review of a more extensive body of European research, Trewavas [27] argued that continued reliance on conventionally-derived animal manures in part nullifies the perceived energy savings associated with organic production.

One long-term North American study found that although there were significant environmental benefits to organic management, adoption of some organic technologies in conventional systems would ameliorate some of the negative environmental impacts associated with conventional systems [10]. This again reinforces the importance of management quality; it may be that a well-managed conventional system could be as good as a typical organic system. Others have also sought more of an ideological and practical middle ground, suggesting that agricultural and environmental sustainability might best be advanced through a combination of organic and conventional practices, even suggesting that organic producers should adopt transgenic crops [76,77]. This is rather unlikely given that the exclusion of genetically modified organisms is one of the central tenets of organic agriculture, but it would nevertheless be short-sighted to neglect the potential for either system to be improved through the ideological or technological contributions of the other.

4. Socio-Economic Aspects of Organic Grain Production on the Canadian Prairies

4.1. Factors Influencing Consumer Preference for Organic Products

The rapid expansion of the organic food industry in North America has been attributed to consumer perceptions that organic food products are healthier and more environmentally friendly than those produced under conventional management. A number of environmental and socio-economic problems have been associated with conventional, high-input cropping systems, and although organic production systems are often believed to have fewer negative impacts, many of the perceived benefits cannot be directly measured and necessitate faith on the part of the consumer.

A global online survey by AC Nielsen found that in North America, nearly 80% of respondents chose organic foods based on a perception that they represented a healthier option, while 11% cited the environmental benefits as their major motivation for choosing organic [78]. This is in contrast to the situation in Europe, where a greater proportion of respondents cited environmental benefits (20%) and animal welfare (12%) as reasons for choosing organic. Interestingly, a Canada-wide survey of consumers’ attitudes and willingness-to-pay for foods with enhanced health benefits reported that while a large proportion of Canadians were willing to pay a premium for the health benefit, when controlled for price, most consumers would choose conventional food products over genetically-modified (GM) or organic products [79]. The same study also found that less than 5% of Canadians were able to correctly answer six knowledge questions about conventional, organic and GM food production practices, which could indicate the preference for conventional food is one based on familiarity. The distribution of consumer valuation of organic foods was broader than for GM foods, consistent with the idea of organic food occupying a niche market in Canada [79]. In an investigation of the role of sensory, health, and environmental information on Canadians' willingness-to-pay for organic wheat bread, Annett *et al.* [80] reported that willingness-to-pay was greater when health information was coupled with sensory evaluation. Overall, sensory evaluations revealed that organic bread was preferred in both blind and fully labeled tests [80], despite the fact that a trained sensory panel detected no differences in color, flavour, or aroma [81].

A few studies have assessed the breadmaking quality of organically grown Canadian wheat. Mason *et al.* [82] compared the breadmaking quality of several Canadian Western Hard Red Spring wheat cultivars grown under organic and conventional management, and found that despite differences in soil nitrogen availability between the management systems, grain protein content was high enough for breadmaking under both organic and conventional management. They also reported a significant management x cultivar interaction for some traits, suggesting it may be possible to breed for high-quality organic wheat. Gelinas *et al.* [83] compared several wheat cultivars under organic management, and concluded that both cultivar and environment played an important role in breadmaking characteristics. Both Gelinas *et al.* [83] and Annett *et al.* [81] reported reduced loaf volume in organic wheat bread, which was consistent with observation by a trained sensory panel that organic wheat bread was more "dense" than conventional bread [81].

Turmel *et al.* [84] reported that crop rotation and management system both played a role in the mineral nutrient content of wheat produced under organic and conventional management, but no direct comparison of breadmaking or nutritional quality was made. In a comparison of five Canadian spring wheat cultivars, Nelson *et al.* [85] reported higher grain Zn, Fe, Mg and K levels in organically produced grain. Turmel *et al.* [84] also reported increased Zn content in organically managed wheat, but there was an interactive effect between management system and crop rotation. The various interactions between management system and crop rotation [84], environmental conditions [83] and cultivars [82], highlight the potential complications inherent in making valid nutritional comparisons between organic and conventional food. Such complexities have also been recognized by other authors attempting to review the larger body of international literature comparing the nutritional and sensory attributes of organic *vs.* conventional food [27,86]. Bourn and Prescott [86] examined a variety of nutritional, sensory, and food safety studies covering a wide range of organic and conventionally produced food products, and concluded that overall, there was little evidence to support the perception that organic foods are nutritionally superior. Might this be cause for concern about the sustainability of the health and nutrition-driven North American organic marketplace?

Organic agriculture is a process, and its standards only dictate what is acceptable in relation to the production process, not the end product itself. No testing is required, for instance, to verify that the end product meets the consumer's perception that it is indeed nutritionally superior and untainted by pesticides or genetically modified organisms. Given the difficulty of truly isolating an organic system from its conventional surroundings, and the likely ongoing dependence of organic production systems on some conventional by-products (*i.e.*, manure; [71]), it is questionable whether process standards alone will be sufficient to sustain consumer confidence in organic food products over the long-term. As consumer awareness about organic agriculture and its standards increases, it is possible that consumers will increasingly demand the implementation of product standards on organic food, which is subject to price premiums based on the (perhaps unjustified) perception that it is superior to its conventional counterparts. Cranfield *et al.* [87] evaluated Canadian consumer preferences of production standards for organic apples, and found that respondents preferred an organic standard that required testing of apples for pesticide residue, in contrast to the current Canadian organic process standard which only prohibits the use of pesticides on organic farms. Such product standards would undoubtedly have consequences on the price of organic food and could impact the affordability for at least some of the current market share.

4.2. Factors Influencing the Economic Sustainability of Organic Producers

For producers, the profitability and financial stability of their operation is of paramount concern and is often a driving influence in management decisions. Although the reduction in yield under organic management is often a concern, several other factors work in favour of increased profitability of crops under organic management. Overall input costs are generally lower for organic systems, in spite of increased seed and equipment costs associated with cultural and mechanical weed control [9,10,88]. Such gains are not unique to organic systems, however, as it has been shown that reduced inputs, particularly of nitrogen, can also increase economic margins under conventional management [11,89].

Price premiums are a major factor in determining the profitability of organic systems in general, and specifically in relation to comparable conventional rotations. For example, Smith *et al.* [88] found that the relative profitability of several organic and conventional crop rotations was heavily dependent on the value of the price premium for the organic product. The net returns for the most profitable organic rotation tested (wheat-peas-oilseed-sweet clover) only exceeded that of the most profitable conventional rotation (continuous wheat) when price premiums on the organic product were high (50–60%). Long term economic analyses of the Rodale Institute Farming Systems Trial in the United States suggested that although net returns for an organic corn-soybean system were lower than a conventional corn-soybean system when all explicit, transitional and labour costs were taken into account, the premium required to offset this difference was only about 10%, much lower than the typical premium of 65–140% for organic grains [10].

While some may question whether such high premiums can be sustained, others have argued that organic food prices better reflect the range of production, processing, distribution and environmental costs that remain externalized in conventional systems and artificially deflate the price of conventional food [9]. Nevertheless, it seems likely that as more producers enter the organic market, increasing supply will force a reduction in some production premiums. Furthermore, as marketing of organic food products increasingly moves from direct sales (*i.e.*, farmer's markets, community supported agriculture) into supermarkets, other players in the food distribution chain will likely capture a share of the premiums. Currently in Canada, sales of organic products in supermarkets account for about 40% of the value of the organic market [4], and more than two-thirds of each consumer dollar is captured by the food distribution and retail system [9]. Thus, the trend toward more mainstream marketing of organic food products may result in a shift of the economic benefits from the producer to the retail sector, while at the same time, increased production resulting from the mass-market demand may lead to a reduction in production premiums. On the other hand, many organic producers have expressed concern; suggesting the lack of developed distribution and marketing infrastructure for organic products represent a major constraint on the industry [19-21,90].

5. Conclusions

Despite the tremendous growth in demand for organic food products in the North American marketplace and a widespread perception that organic agriculture represents a more sustainable alternative to conventional production systems, questions remain about the long-term sustainability of organic grain production on the Canadian Prairies. Cropping system comparisons are inherently challenging for reductionist science, since both organic and conventional systems are characterized by a range of management practices which vary according to site-specific requirements and farmer choice. For example, although the absence of synthetic fertilizers and pesticides is a defining characteristic common to all organic systems, there is considerable diversity in crop choice, rotation, and other management practices, the sum of which determine the placement of farms along a spectrum of "organic production systems". While such diversity makes generalizations difficult, there are a number of practices commonly different between organic and conventional systems which nevertheless make such comparisons valuable.

Considerable strides have been made toward addressing the agronomic challenges inherent in organic systems, including weed control and soil fertility management, but more work is needed to ensure that production is sustainable over the long-term. Further research is needed to fully understand the impacts of long-term organic management on soil phosphorous availability, and to optimize cropping systems and management standards accordingly. Integrated crop-livestock systems [72] may play an important role in maintaining soil nutrients on organic farms and more research will be needed to determine the best practices for organic systems on the Canadian Prairies.

Concerns about soil conservation still need to be addressed through the development of methods to further reduce soil disturbance from tillage. The benefits of zero-tillage have long been recognized in conventional systems [26,69], and although adoption of zero-tillage in conventional systems has been greatly assisted by the use of herbicides for weed control, high-input costs are supporting a shift toward reduced input systems. In terms of long-term sustainability, such well-managed conventional systems may rival some organically managed systems.

The development of more competitive cultivars suitable for organic production would likely also benefit such reduced-input conventional systems. Some authors have argued that the focus on genetic engineering as a technological paradigm has in fact hindered agroecological innovations which are vital to the sustainability of agricultural systems [91]. There is some merit in the suggestion that certain agricultural research policies and funding priorities do greatly favour biotechnological approaches, but there may be some room for an ideological middle ground and a willingness for both organic and conventional systems to adopt innovations that are mutually beneficial. Conventional systems may benefit greatly from adoption of low-input agronomic strategies borrowed from organic systems, allowing for a reduced input system which can realize many of the environmental benefits of organic systems, such as increased energy efficiency and reduced greenhouse gas emissions.

From the perspective of advancing overall agricultural sustainability and productivity, this would seem to be a prudent approach, but for organic systems in particular, this may be difficult to achieve while preserving the "identity" of organic agriculture as something recognizably distinct from conventional systems. Given the importance of price premiums for ensuring the economic viability of organic producers, preservation of this high-value niche market will be important for the ongoing sustainability of organic production. For the same reason, the organic sector may need to address the issue of relying solely on process standards in its certification requirements [87].

There is also a need for greater consumer education on agricultural production systems. This has been recognized by both organic producers [19-21] and market researchers [79]. While there is growing awareness of both health and environmental issues associated with agricultural production, many Canadians are unaware of the differences between different production systems [79], and there is little recognition of the large externalized costs of conventional systems [9].

A full accounting of the costs associated with high-input conventional systems must consider the range of negative impacts, including reduced ground and surface water quality, crop pest problems, soil erosion, energy use, high input costs and compromised farm economic resilience. If we consider sustainable agriculture to include systems which permit indefinite future use without causing irrecoverable degradation of resources and biological integrity [92], it is clear that conventional systems relying on synthetic inputs are not sustainable over the long-term. Organic production systems offer a good alternative, but the extensive nature and commodity-driven reality of Prairie grain production may limit its widespread adoption.

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References and Notes

1. IFOAM. *The IFOAM Basic Norms for Organic Production and Processing Version 2005*; Available online: http://www.ifoam.org/about_ifoam/standards/norms/norm_documents_library/Norms_ENG_V4_20090113.pdf (access on 16 January 2010).
2. Willer, H. The world of organic agriculture 2009: Summary. In *The World of Organic Agriculture: Statistics and Emerging Trends 2009*; Willer, H., Klicher, L., Eds.; IFOAM: Bonn, Germany; FiBL: Frick, Switzerland; ITC: Geneva, Switzerland, 2009; pp. 19-24.
3. Sahota, A. Overview of the Global Market for Organic Food and Drink. In *The World of Organic Agriculture: Statistics and Emerging Trends 2004*; Willer, H., Yussefi, M., Eds.; International Federation of Organic Agriculture Movements: Bonn, Germany, 2004; pp. 21-26.
4. Macey, A. *Retail Sales of Certified Organic Food Products in Canada in 2006*; Available online: http://www.organicagcentre.ca/Docs/RetailSalesOrganic_Canada2006.pdf (access on 30 December 2009).
5. Canadian Food Inspection Agency. *Organic Products*; Available online: http://www.inspection.gc.ca/english/fssa/orgbio/orgbioe.shtml (access on 19 December 2009).

6. Kendrick, J. *Organic: From Niche to Mainstream (Statistics Canada: Canadian Agriculture at a Glance)*; Available online: http://www.statcan.gc.ca/bsolc/olc-cel/olc-cel?lang=eng&catno=96-325-X200700010529 (access on 17 January 2010).
7. Entz, M.H.; Guilford, R.; Gulden, R. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. *Can. J. Plant Sci.* **2001**, *81*, 351-354.
8. Nelson, A.; Froese, J.; Beavers, R.L. *Lowering Soil Erosion Risk in Organic Cropping Systems*; Final Research Report W2006-09; Available online: http://www.organicagcentre.ca/Docs/OACC_bulletins06/OACC_Bulletin9_erosion_risk.pdf (access on 26 February 2010).
9. Macrae, R.J.; Frick, B.; Martin, R.C. Economic and social impacts of organic production systems. *Can. J. Plant Sci.* **2007**, *87*, 1037-1044.
10. Pimentel, D.; Hepperly, P.; Hanson, J.; Douds, D.; Seidel, R. Environmental, energetic, and economic comparisons of organic and conventional farming systems. *Bioscience* **2005**, *55*, 573-582.
11. Khakbazan, M.; Mohr, R.M.; Derksen, D.A.; Monreal, M.A.; Grant, C.A.; Zentner, R.P.; Moulin, A.P.; McLaren, D.L.; Irvine, R.B.; Nagy, C.N. Effects of alternative management practices on the economics, energy and GHG emissions of a wheat-pea cropping system in the Canadian prairies. *Soil Till. Res*. **2009**, *104*, 30-38.
12. Pelletier, N.; Arsenault, N.; Tyedmers, P. Scenario Modeling Potential Eco-Efficiency Gains from a Transition to Organic Agriculture: Life Cycle Perspectives on Canadian Canola, Corn, Soy, and Wheat Production. *Environ. Manage.* **2008**, *42*, 989-1001.
13. Agriculture and Agri-Food Canada. *Sustainable Agriculture: Our Path Forward*; Available online: http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1175533355176&lang=eng (access on 30 December 2009).
14. Rodale Institute. *Organic or "Natural"*; Available online: http://www.rodaleinstitute.org/organic_or_natural (access on 7 February 2010).
15. IFOAM. *Principles of Organic Agriculture*; Available online: http://www.ifoam.org/about_ifoam/principles/index.html (access on 16 January 2010).
16. Sustainable Table. *The Issues: Organic*; Available online: http://www.sustainabletable.org/issues/organic/ (access on 7 February 2010).
17. Statistics Canada. *Total Area of Farms, Land Tenure and Land in Crops, by Province*; Available online: http://www40.statcan.ca/l01/cst01/agrc25a.htm (access on 26 February 2010).
18. Macey, A. *Certified Organic Production in Canada*, 2004; Available online: http://www.cog.ca/documents/certified_organic_production_2004_report.pdf (access on 26 February 2010).
19. Frick, B.; Beavers, R.L.; Hammermeister, A.M.; Thiessen-Martens, J.R. *Research Needs Assessment of Saskatchewan Organic Farmers*; Available online: http://www.organicagcentre.ca/Docs/Saskatchewan%20Research%20Needs%20Survey%20with%20cover.pdf (access on 13 December 2009).
20. Organic Agriculture Centre of Canada. *Research Needs Assessment of Manitoba Organic Farmers*; Available online: http://oacc.info/Docs/Manitoba%20Research%20Needs%20Survey%20Final%20Report_dec08.pdf (access on 13 December 2009).

21. Organic Agriculture Centre of Canada. *Research Needs Assessment of Alberta Organic Farmers*; Available online: http://www.organicagcentre.ca/Docs/Alberta%20survey%20Nov12.pdf (access on 13 December 2009).
22. Canadian Organic Growers Economics of Organic Farming. In *Organic Field Crop Handbook*; Wallace, J., Ed.; Canadian Organic Growers: Ottawa, ON, Canada, 2001; pp. 8-10.
23. Mason, H.E.; Spaner, D. Competitive ability of wheat in conventional and organic management systems: A review of the literature. *Can. J. Plant Sci.* **2006**, *86*, 333-343.
24. Johnson, E.; Wolf, T.; Caldwell, B.; Barbour, R.; Holm, R.; Sapsford, K. Efficacy of vinegar (acetic acid) as an organic herbicide (ADF Project # 20020202, AAFC Project # A03637); Available online: http://www.agr.gov.sk.ca/apps/adf/adf_admin/reports/20020202.pdf (access on 31 December 2009).
25. Bailey, K.; Johnson, E.; Kutcher, R.; Braaten, C. *An Organic Option for Broadleaved Weed Control in Cereals Using a Microbial Herbicide*; Interim Report; Organic Sector Market Development Initiative (OSMDI), Canadian Wheat Board: Manitoba, Canada, 2009; Available online: http://www.organicagcentre.ca/Docs/OSMDI%20Oct%202009%20Bailey%20Interim%20Report.pdf (access on 31 December 2009).
26. Lafond, G.P.; Derksen, D.A. Long-term potential of conservation tillage on the Canadian prairies. *Can. J. Plant Pathol.* **1996**, *18*, 151-158.
27. Trewavas, A. A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. *Crop Prot.* **2004**, *23*, 757-781.
28. Teasdale, J.R.; Coffman, C.B.; Mangum, R.W. Potential Long-Term Benefits of No-Tillage and Organic Cropping Systems for Grain Production and Soil Improvement. *Agron. J.* **2007**, *99*, 1297-1305.
29. Blackshaw, R.E. Tillage intensity affects weed communities in agroecosystems. In *Invasive Plants: Ecological and Agricultural Aspects*; Inderjit, S., Ed.; Birkhauser Verlag: Basel, Switzerland, 2005; pp. 209-221.
30. Nelson, A. *Soil Erosion Risk and Mitigation through Crop Rotation on Organic and Conventional Cropping Systems*; M.Sc. Thesis; University of Manitoba: Winnipeg, MB, Canada, 2005.
31. Entz, M.H.; Baron, V.S.; Carr, P.M.; Meyer, D.W.; Smith, S.R.; McCaughey, W.P. Potential of forages to diversify cropping systems in the northern Great Plains. *Agron. J.* **2002**, *94*, 240-250.
32. Smil, V. *Feeding the World: A Challenge for the Twenty-First Century*; The MIT Press: Cambridge, MA, USA, 2000.
33. Wiens, M.J.; Entz, M.H.; Martin, R.C.; Hammermeister, A.M. Agronomic benefits of alfalfa mulch applied to organically managed spring wheat. *Can. J. Plant Sci.* **2006**, *86*, 121-131.
34. Malhi, S.S.; Brandt, S.A.; Lemke, R.; Moulin, A.P.; Zentner, R.P. Effects of input level and crop diversity on soil nitrate-N, extractable P, aggregation, organic C and N, and nutrient balance in the Canadian Prairie. *Nutr. Cycl. Agroecosyst.* **2009**, *84*, 1-22.
35. Blackshaw, R.E.; Moyer, J.R.; Doram, R.C.; Boswell, A.L. Yellow sweetclover, green manure, and its residues effectively suppress weeds during fallow. *Weed Sci.* **2001**, *49*, 406-413.
36. Blackshaw, R.E.; Moyer, J.R.; Doram, R.C.; Boswall, A.L.; Smith, E.G. Suitability of undersown sweetclover as a fallow replacement in semiarid cropping systems. *Agron. J.* **2001**, *93*, 863-868.

37. Blackshaw, R.E.; Molnar, L.J.; Moyer, J.R. Suitability of legume cover crop-winter wheat intercrops on the semi-arid Canadian Prairies. *Can. J. Plant Sci.* 2010, (in press).
38. Moyer, J.R.; Blackshaw, R.E.; Huang, H.C. Effect of sweetclover cultivars and management practices on following weed infestations and wheat yield. *Can. J. Plant Sci.* **2007**, *87*, 973-983.
39. O'Donovan, J.T.; Blackshaw, R.E.; Harker, K.N.; Clayton, G.W.; Moyer, J.R.; Dosdall, L.M.; Maurice, D.C.; Turkington, T.K. Integrated approaches to managing weeds in spring-sown crops in western Canada. *Crop Prot.* **2007**, *26*, 390-398.
40. O'Donovan, J.T.; Blackshaw, R.E.; Harker, K.N.; Clayton, G.W.; McKenzie, R. Variable crop plant establishment contributes to differences in competitiveness with wild oat among cereal varieties. *Can. J. Plant Sci.* **2005**, *85*, 771-776.
41. Nazarko, O.M.; Van Acker, R.C.; Entz, M.H. Strategies and tactics for herbicide use reduction in field crops in Canada: A review. *Can. J. Plant Sci.* **2005**, *85*, 457-479.
42. O'Donovan, J.T.; Harker, K.N.; Clayton, G.W.; Newman, J.C.; Robinson, D.; Hall, L.M. Barley seeding rate influences the effects of variable herbicide rates on wild oat. *Weed Sci.* **2001**, *49*, 746-754.
43. Blackshaw, R.E.; Beckie, H.J.; Molnar, L.J.; Entz, T.; Moyer, J.R. Combining agronomic practices and herbicides improves weed management in wheat-canola rotations within zero-tillage production systems. *Weed Sci.* **2005**, *53*, 528-535.
44. Harker, K.N.; Clayton, G.W.; Blackshaw, R.E.; O'Donovan, J.T.; Stevenson, F.C. Seeding rate, herbicide timing and competitive hybrids contribute to integrated weed management in canola (*Brassica napus*). *Can. J. Plant Sci.* **2003**, *83*, 433-440.
45. Smith, E.G.; Upadhyay, B.M.; Blackshaw, R.E.; Beckie, H.J.; Harker, K.N.; Clayton, G.W. Economic benefits of integrated weed management systems for field crops in the Dark Brown and Black soil zones of western Canada. *Can. J. Plant Sci.* **2006**, *86*, 1273-1279.
46. Blackshaw, R.E.; Harker, K.N.; O'Donovan, J.T.; Beckie, H.J.; Smith, E.G. Ongoing development of integrated weed management systems on the Canadian prairies. *Weed Sci.* **2008**, *56*, 146-150.
47. Mason, H.; Navabi, A.; Frick, B.; O'Donovan, J.; Spaner, D. Cultivar and seeding rate effects on the competitive ability of spring cereals grown under organic production in northern Canada. *Agron. J.* **2007**, *99*, 1199-1207.
48. Beavers, R.L.; Hammermeister, A.M.; Frick, B.; Astatkie, T.; Martin, R.C. Spring wheat yield response to variable seeding rates in organic farming systems at different fertility regimes. *Can. J. Plant Sci.* **2008**, *88*, 43-52.
49. Baird, J.M.; Shirtliffe, S.J.; Walley, F.L. Optimal seeding rate for organic production of lentil in the northern Great Plains. *Can. J. Plant Sci.* **2009**, *89*, 1089-1097.
50. Baird, J.M.; Walley, F.L.; Shirtliffe, S.J. Optimal seeding rate for organic production of field pea in the northern Great Plains. *Can. J. Plant Sci.* **2009**, *89*, 455-464.
51. Kaut, A.H.E.E.; Mason, H.E.; Navabi, A.; O'Donovan, J.T.; Spaner, D. Organic and conventional management of mixtures of wheat and spring cereals. *Agron. Sustain. Dev.* **2008**, *28*, 363-371.
52. Pridham, J.C.; Entz, M.H.; Martin, R.C.; Hucl, R.J. Weed, disease and grain yield effects of cultivar mixtures in organically managed spring wheat. *Can. J. Plant Sci.* **2007**, *87*, 855-859.

53. Kaut, A.H.E.E.; Mason, H.E.; Navabi, A.; O'Donovan, J.T.; Spaner, D. Performance and stability of performance of spring wheat variety mixtures in organic and conventional management systems in western Canada. *J. Agr. Sci.* **2009**, *147*, 141-153.
54. Pridham, J.C.; Entz, M.H. Intercropping spring wheat with cereal grains, legumes, and oilseeds fails to improve productivity under organic management. *Agron. J.* **2008**, *100*, 1436-1442.
55. Murphy, K.M.; Dawson, J.C.; Jones, S.S. Relationship among phenotypic growth traits, yield and weed suppression in spring wheat landraces and modern cultivars. *Field Crop Res.* **2008**, *105*, 107-115.
56. Mason, H.E.; Navabi, A.; Frick, B.L.; O'Donovan, J.T.; Spaner, D.M. The weed-competitive ability of Canada western red spring wheat cultivars grown under organic management. *Crop Sci.* **2007**, *47*, 1167-1176.
57. Mason, H.; Goonewardene, L.; Spaner, D. Competitive traits and the stability of wheat cultivars in differing natural weed environments on the northern Canadian Prairies. *J. Agr. Sci.* **2008**, *146*, 21-33.
58. Reid, T.A.; Navabi, A.; Cahill, J.C.; Salmon, D.; Spaner, D. A genetic analysis of weed competitive ability in spring wheat. *Can. J. Plant Sci.* **2009**, *89*, 591-599.
59. Reid, T.A.; Yang, R.C.; Salmon, D.F.; Spaner, D. Should spring wheat breeding for organically managed systems be conducted on organically managed land? *Euphytica* **2009**, *169*, 239-252.
60. Murphy, K.M.; Campbell, K.G.; Lyon, S.R.; Jones, S.S. Evidence of varietal adaptation to organic farming systems. *Field Crop Res.* **2007**, *102*, 172-177.
61. Canadian General Standards Board. *Organic Production Systems General Principles and Management Standards*; Available online: http://www.organicagcentre.ca/Docs/Cdn_Stds_Principles2006_e.pdf (access on 16 January 2010).
62. Martin, R.C.; Lynch, D.; Frick, B.; van Straaten, P. Phosphorous status on Canadian organic farms. *J. Sci. Food Agric.* **2007**, *87*, 2737-2740.
63. Malhi, S.S.; Brandt, S.A.; Ulrich, D.; Lemke, R.; Gill, K.S. Accumulation and distribution of nitrate-nitrogen and extractable phosphorous in the soil profile under various alternative cropping systems. *J. Plant Nutr.* **2002**, *25*, 2499-2520.
64. Kabir, Z.; OHalloran, I.P.; Fyles, J.W.; Hamel, C. Seasonal changes of arbuscular mycorrhizal fungi as affected by tillage practices and fertilization: Hyphal density and mycorrhizal root colonization. *Plant Soil* **1997**, *192*, 285-293.
65. Douds, D.D.; Galvez, L.; Franke-Snyder, M.; Reider, C.; Drinkwater, L.E. Effect of compost addition and crop rotation point upon VAM fungi. *Agr. Ecosyst. Environ.* **1997**, *65*, 257-266.
66. Brechelt, A. Effect of Different Organic Manures on the Efficiency of Va Mycorrhiza. *Agr. Ecosyst. Environ.* **1990**, *29*, 55-58.
67. Hamel, C.; Strullu, D.G. Arbuscular mycorrhizal fungi in field crop production: Potential and new direction. *Can. J. Plant Sci.* **2006**, *86*, 941-950.
68. Nelson, A.; Spaner, D. Cropping systems management, soil microbial communities, and soil biological fertility: A review. In *Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming, Sustainable Agriculture Reviews 4*; Lichtfouse, E., Ed.; Springer Science+Business Media B.V.: Dordrecht, The Netherlands, 2010.

69. Clapperton, M.J.; Yin Chan, K.; Larney, F.J. Managing the soil habitat for enhanced biological fertility. In *Soil Biological Fertility—A Key to Sustainable Land Use in Agriculture*; Abbott, L.K., Murphy, D.V., Eds.; Springer: Dordrecht, The Netherlands, 2007; pp. 203-222.
70. Welsh, C.; Tenuta, M.; Flaten, D.N.; Thiessen-Martens, J.R.; Entz, M.H. High Yielding Organic Crop Management Decreases Plant-Available but Not Recalcitrant Soil Phosphorus. *Agron. J.* **2009**, *101*, 1027-1035.
71. Duval, J. Co-dependency between Organic and Conventional Agriculture: Transient or Long-lasting? Available online: http://www.organicagcentre.ca/Docs/DiscussionPapers09/Codependency%20final%20version.pdf (access on 18 January 2010).
72. Russelle, M.P.; Entz, M.H.; Franzluebbers, A.J. Reconsidering Integrated Crop-Livestock Systems in North America. *Agron. J.* **2007**, *99*, 325-334.
73. Entz, M.H.; Hoeppner, J.W.; Wilson, L.; Tenuta, M.; Bamford, K.C.; Holliday, N. Influence of organic management with different crop rotations on selected productivity parameters in a long-term Canadian field study. In *Researching Sustainable Systems, Proceedings of the International Scientific Conference on Organic Agriculture*, Adeledaide, Australia, 21–23 September 2005.
74. Lynch, D. Environmental impacts of organic agriculture: A Canadian perspective. *Can. J. Plant Sci.* **2009**, *89*, 621-628.
75. Hoeppner, J.W.; Entz, M.H.; McConkey, B.G.; Zentner, R.P.; Nagy, C.N. Energy use and efficiency in two Canadian organic and conventional crop production systems. *Renew. Agr. Food Syst.* **2006**, *21*, 60-67.
76. Ammann, K. Why farming with high tech methods should integrate elements of organic agriculture. *New Biotechnol.* **2009**, *25*, 378-388.
77. Ammann, K. Integrated farming: why organic farmers should use transgenic crops. *New Biotechnol.* **2008**, *25*, 101-107.
78. AC Nielsen. *Functional Foods and Organics: A Global AC Nielsen Online Survey on Consumer Behavior and Attitudes*; Available online: http://it.nielsen.com/trends/2005_cc_functional_organics.pdf.pdf (access on 17 January 2010).
79. West, G.E.; Gendron, C.; Larue, B.; Lambert, R. Consumers' valuation of functional properties of foods: Results from a Canada-wide survey. *Can. J. Agr. Econ.* **2002**, *50*, 541-558.
80. Annett, L.E.; Muralidharan, V.; Boxall, P.C.; Cash, S.B.; Wismer, W.V. Influence of health and environmental information on hedonic evaluation of organic and conventional bread. *J. Food Sci.* **2008**, *73*, H50-H57.
81. Annett, L.E.; Spaner, D.; Wismer, W.V. Sensory profiles of bread made from paired samples of organic and conventionally grown wheat grain. *J. Food Sci.* **2007**, *72*, S254-S260.
82. Mason, H.; Navabi, A.; Frick, B.; O'Donovan, J.; Niziol, D.; Spaner, D. Does growing Canadian Western Hard Red Spring wheat under organic management alter its breadmaking quality? *Renew. Agr. Food Syst.* **2007**, *22*, 157-167.
83. Gelinas, P.; Morin, C.; Reid, J.F.; Lachance, P. Wheat cultivars grown under organic agriculture and the bread making performance of stone-ground whole wheat flour. *Int. J. Food Sci. Technol.* **2009**, *44*, 525-530.

84. Turmel, M.S.; Entz, M.H.; Bamford, K.C.; Martens, J.R.T. The influence of crop rotation on the mineral nutrient content of organic *vs.* conventionally produced wheat grain: Preliminary results from a long-term field study. *Can. J. Plant Sci.* **2009**, *89*, 915-919.
85. Nelson, A.; Quideau, S.; Frick, B.; Hucl, P.; Thavarajah, D.; Clapperton, J.; Spaner, D. The soil microbial community and grain micronutrient content of wheat grown organically and conventionally. *Can. J. Plant Sci*. 2010, (submitted).
86. Bourn, D.; Prescott, J. A comparison of the nutritional value, sensory qualities, and food safety of organically and conventionally produced foods. *Crit. Rev. Food Sci.* **2002**, *42*, 1-34.
87. Cranfield, J.; Deaton, B.J.; Shellikeri, S. Evaluating Consumer Preferences for Organic Food Production Standards. *Can J. Agr. Econ.* **2009**, *57*, 99-117.
88. Smith, E.G.; Clapperton, M.J.; Blackshaw, R.E. Profitability and risk of organic production systems in the northern Great Plains. *Rene. Agr. Food Syst.* **2004**, *19*, 152-158.
89. Khakbazan, M.; Grant, C.A.; Irvine, R.B.; Mohr, R.M.; McLaren, D.L.; Monreal, M. Influence of alternative management methods on the economics of flax production in the Black Soil Zone. *Can. J. Plant Sci.* **2009**, *89*, 903-913.
90. Degenhardt, R.; Martin, R.; Spaner, D. Organic farming in Central Alberta: Current trends, production constraints and research needs. *J. Sustain. Agr.* **2005**, *27*, 153-173.
91. Vanloqueren, G.; Baret, P.V. How agricultural research systems shape a technological regime that develops genetic engineering but locks out agroecological innovations. *Res. Policy* **2009**, *38*, 971-983.
92. Love, B.; Spaner, D. Agrobiodiversity: Its value, measurement, and conservation in the context of sustainable agriculture. *J. Sustain. Agr.* **2007**, *31*, 53-82.