University of Alberta

Soil microbial communities and grain quality as affected by spring wheat (*Triticum aestivum* L.) cultivar and grain mixtures in organic and conventional management systems

by

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A thesis submitted to the Faculty of Graduate Studies and Research
in partial fulfillment of the requirements for the degree of

Doctor of Philosophy
in
Plant Science

Department of Agricultural, Food and Nutritional Science

Fall 2011
Edmonton, Alberta

Abstract

It may be possible to tailor crop management to encourage diverse soil microbial communities and beneficial microorganisms, and produce high quality food products. Studies were carried out in 2005-2007 to evaluate the impact of spring wheat (*Triticum aestivum L.*) cultivar choice and crop polycultures on soil microbial communities in organic and conventional systems, and subsequent wheat quality. Five wheat cultivars were grown organically and conventionally to evaluate grain breadmaking quality and micronutrient content and their impact on the soil microbial community. Organic grain yields were roughly half of conventional yields, but quality levels were all acceptable for Canadian Western Hard Red Spring wheat. Measured soil (0-15 cm) microbial profiles (by phospholipid fatty acid analysis) differed between the two management systems, and amongst cultivars in the conventional system. The most recent cultivar in the study, AC Superb, exhibited the highest levels of fungi suggesting that breeding efforts in conventionally managed environments may have resulted in cultivating mycorrhizal dependence in that environment. In general, many of the studied grain micronutrients were greater in the organically grown wheat system, possibly due in part to decreased grain yield and smaller grain size. Maximizing grain micronutrient content through wheat cultivar choice was dependent on management system. The presence of fungi biomarkers appears to have improved uptake of Mn and Cu**.** Monocultures and polycultures of common annual crops were grown organically and conventionally in 2006-2007. Intercrops exhibited an ability to overyield in an organic system, largely through weed suppression, but intercrops also overyielded in a conventional system where weeds were controlled through herbicides. As intercrop complexity decreased, the instances of improved weed suppression declined. Management systems and wheat cultivars can alter the composition of the soil microbial community. Annual crop

polycultures did not alter soil microbial communities in this study, but showed evidence of agronomic benefits in both organic and conventional systems.

Acknowledgement

This thesis research would not have been possible without help from a number of individuals and organizations.

Thank you to Dean Spaner. He generously gave me his time, guidance and support throughout this project, helping me grow as a scientist and as an individual. I am honored to have worked with him.

Thank you to Brenda Frick, Sylvie Quideau and Jill Clapperton for their help, suggestions and comments throughout the development and writing of this thesis.

Thank you to Alireza Navabi, Klaus Strenzke, Cliff Therou, Derrick Kanashiro, Jennifer Lloyd, David Niziol and Dil Thavarajah for their technical support of my field and laboratory work.

Thank you also to Brian, Holley, Frances, Carla, Alana, Corrina, and Madison for their assistance with the summer field work.

I am very grateful to Steven Snider and James Penner for allowing me to conduct field trials on their land.

Thank you to my colleagues, Heather, Amy, Todd, Iqbal, Klaus, Atif and Hiro, for their help, advice, fun times and philosophical talks.

My parents have always been there with love, support, encouragement, guidance and interest in what I choose to do. Thank you.

Thank you Travis, for everything.

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1.1 Introduction

Consumers are becoming increasingly concerned with food safety, the presence of pesticides and genetically modified organisms in their grain products, and the negative environmental effects of conventional agriculture (Klonsky 2000). This increase in suspicion of industrial food production systems has, in part, translated into increased demand for organic food products. In Canada, there are now over 3600 organic farms on more than 500,000 hectares (Macey 2006). The organic market in Canada has been growing by 15-20% per year since the late 1990's, while the food industry overall has grown 2% per year from 1992 to 2000 (Sahota et al. 2004; Klonsky 2000).

Consumers purchase organic food products because they perceive these foods to have unique and/or superior quality attributes than conventional foods (Yiridoe et al. 2005). Modern, high-input cropping systems have created numerous environmental, social and economic problems, including groundwater contamination, increased farm specialization, exacerbation of crop pest problems, soil erosion, energy dependency, high input expenses, less farm economic resilience and eutrophication of surface waters (Soule and Piper 1992; McRae et al. 2000). One principle of organic agriculture is the maintenance of biological diversity (CGSB 2006). However, organic systems of production may or may not increase soil biodiversity, as many of the perceived attributes of organic products cannot be or have not been adequately measured, and necessitate faith on the part of the consumer that the desired attributes are present (Ritson and Oughton 2007).

Soil microbes play important roles in agroecosystems. This review is concerned with the microflora in the soil system, which are the smallest organisms in the soil and include bacteria, actinomycetes, fungi and algae. The soil is a habitat for large numbers of diverse soil microbes. Within a gram of soil there can be thousands of millions of fungi and bacteria, where about 95% of the species in the soil remain unknown (Uphoff et

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[1] *A version of this chapter has been published. Nelson, A. G. and Spaner, D. 2010. In E. Lichtfouse (ed.), Genetic Engineering, Biofertilisation, Soil Quality and Organic Farming, Sustainable Agriculture Reviews 4:217-242.*

al. 2006). Bacteria and archaea are single-celled microbes, and have roles in organic matter decomposition; biological transformation of nutrients; as well as some plant, animal or other soil microbe symbionts. Fungi are present in many forms in the soil, and have many roles within the soil system, including plant or animal symbionts, organic matter decomposition, soil aggregation, plant and animal pathogens, etc. Actinomycetes are a particular form of prokaryote whose morphology resembles that of fungi; they have roles in soil aggregation, production of antibiotic compounds, organic matter turnover and nitrogen fixation (Brady and Weil 2002). Algae have roles in the cycling of carbon, nitrogen and water; stabilizing soil and forming symbiotic associations with plants (Belnap 2005).

Soil fertility refers to the soil's ability to supply nutrients to crops growing in it (Watson et al. 2002). Soil microbes affect soil fertility in many ways, including: plant symbioses with arbuscular mycorrhizal fungi and *Rhizobia* bacteria, organic matter turnover, mineral immobilization and dissolution, and soil aggregation (Davis and Abbott 2006). Managing soil biological fertility may be a key to successful sustainable agricultural systems producing high quality food products (Lee and Pankhurst 1992).

For environmental and economic reasons in addition to market demand, improvements in cropping systems and the food products they create must be achieved through improvements in the efficiency of natural nutrient cycling, not through the use of additional inputs (Patriquin 1986; Yeates et al. 1997; Galvez et al. 1995). Soil microbial communities have a large role in nutrient cycling, and can be affected by agricultural management practices. It may be possible and feasible to tailor cropping systems management to encourage diverse microbial communities and specific beneficial microorganisms, and thereby promote efficient nutrient cycling and plant nutrient uptake. This paper will discuss some of the roles of soil microbial diversity and mycorrhizae in nutrient cycling and plant nutrient uptake, and review the literature on the effects of management practices on soil microbial diversity and mycorrhizal colonization in agricultural systems. We will then examine the impact of combining the reviewed management practices on microbial diversity in organic and conventional cropping systems. We will discuss the feasibility of managing an agroecosystem for soil biodiversity.

1.2 Soil Microbiological Diversity in Agroecosystems

Plants are autotrophs, creating the organic molecules they require for growth and development using elements absorbed mainly from the soil solution (Salisbury and Ross 1992). Plants mainly take up elements in inorganic forms (Schimel and Bennett 2004; Xu et al. 2006). Microbes play a critical role in soil nutrient cycling, decomposing organic matter and mineralizing nutrients into inorganic, plant available forms (Kennedy and Gewin 1997; Prasad and Power 1997; Stark et al. 2004; Uphoff et al. 2006).

Soil microbial diversity can be defined in terms of structural diversity, referring to the organisms present within the community, and functional diversity, referring to the functions carried out by the community. A population refers to a group of organisms of the same species within an environment, while the community refers to the interacting group of organisms within the environment (Figure 1-1). Diversity is a measure of variety of organisms within the community. Soil microbial diversity can impart resistance and resililance to disturbance and stress within agroecosystems (Brussaard et al. 2004 and 2007). Soil fungal communities under organic management were reported to be more resistant to environmental disturbances, such as a hurricane (Wu et al. 2007). One requirement of a well-functioning soil is 'diversified and abundant populations of soil organisms to mobilize nutrients' (Uphoff et al. 2006). Diverse microbial communities more effectively use complex organic compounds, are more efficient carbon users, and are more able to mobilize nitrogen than less complex microbial communities (Bonkowski and Roy 2005). All of these factors suggest that lowered soil microbial diversity will have negative effects on the efficiency of nutrient cycling in the soil (Bonkowski and Roy 2005). The relationship between soil biological diversity and ecosystem functioning has not been fully elucidated (Anderson 2003; Coleman et al. 1994; Robertson and Grandy 2006; Giller et al. 1997). As well, we do not know the relative importance of soil biological diversity on the integrity and sustainability of a given soil system (Welbaum et al. 2004). However, we do know that at some point in the loss of soil microbial diversity there will be a loss of ecosystem functioning (Coleman et al. 1994; Giller et al. 1997). A change in microbial community structure due to disturbance can result in a reduction of soil functional stability (Griffiths et al. 2004). This means that until we know the functions carried out by specific organisms, maintaining diversity is a way of ensuring ecosystem functionability. Numerous studies have examined the effects of agricultural management practices on soil microbial community and diversity. It may be possible to manage an agroecosystem to increase soil biodiversity and soil biological fertility; however, this is mainly managed indirectly. We influence soil microbial communities by altering crop rotations, crop choice, tillage, and inputs (Brussaard et al. 2007).

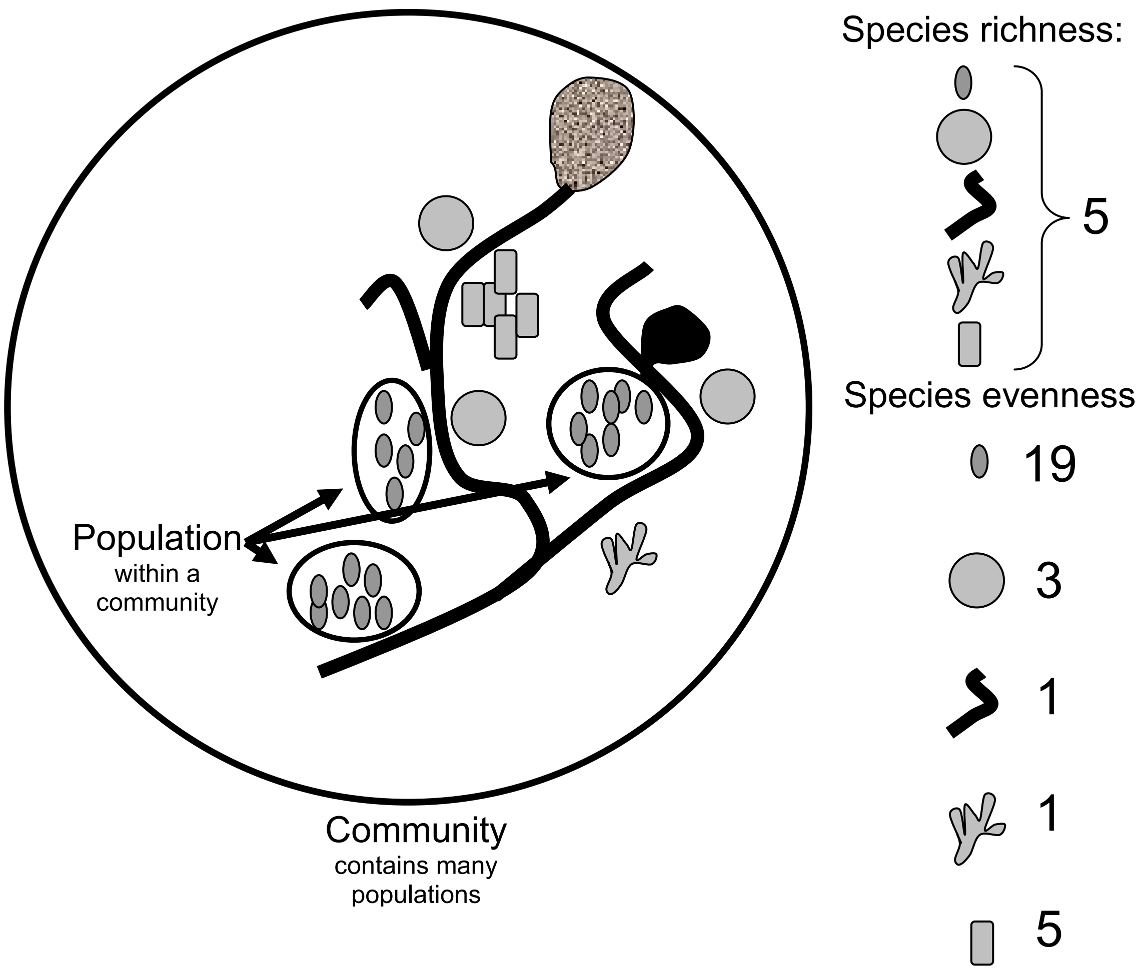


Figure 1-1. A drawing to show the difference between a population, all one species within a soil system, and a community, a grouping of populations within an soil system. A population is present within a community. Species richness is a measure of how many different species are present within a soil system. Species evenness is a measure of how even the numbers of the various species are within a soil system. Diversity is a measure that incorporates both species richness and evenness.

1.3 Arbuscular Mycorrhizal Fungi in Agroecosystems

Within the diverse community of soil microbes, arbuscular mycorrhizal fungi play an important role in nutrient cycling and uptake in crop plants. Arbuscular mycorrhizal fungi form, generally, mutualistic associations with the roots of over 80% of known plant species including wheat and other cereal crops, corn, rice, and legumes (Habte 2006; Rillig 2004). Arbuscular mycorrhizal fungi get their name from the arbuscules, or tree-shaped clusters of hyphae which form within a plant root after infection (Habte 2006). The arbuscles are where nutrient exchange with plants occur; carbon products from the plant host flow to the fungus, while nutrients taken up by the fungus flow to the plant (Sylvia 2005), Figure 1-2. Mycorrhiza are important in nutrient uptake for plants, because the fungal hyphae not within the plant root represent increased surface area for absorption of essential plant nutrients, as well as an increase in the soil area explored. Mycorrhiza can take up a number of nutrients, including: nitrogen, phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, copper and zinc (Al-Karaki et al. 2004; Mohammad et al. 2005; Ryan et al. 2004; Cruz et al. 2004; Mohammad et al. 2003). However, where mycorrhiza are most beneficial is in the uptake of relatively immobile nutrients such as phosphorus, copper and zinc (Habte 2006). The importance of mycorrhiza in the uptake of immobile nutrients is due to the hyphae accessing nutrients that are not within reach of the plant roots, and because these nutrients do not flow to root surfaces by mass flow (Habte 2006). Increased uptake of phosphorus through mycorrhizal colonization can significantly increase phosphorus concentrations in wheat grains, with the intensity of the effect altered by wheat cultivar, mycorrhizal species and the soil environment (Al-Karaki et al. 2004).

In addition to plant nutrient uptake, mycorrhiza can generate a number of other benefits to the soil system and the plant. Some other benefits of mycorrhiza within the soil system are: stabilization of soil aggregates, suppression of plant fungal pathogens, reduction of plant parasitic infection by nematodes, protection of plants from drought and saline conditions, and protection of plants from heavy metals (Habte 2006). Mycorrhiza also have an effect on the community structure of other soil microorganisms, by contributing carbon compounds to the soil system as well as influencing soil structure (Hamel 2004; Hamel and Strullu 2006). The benefits of mycorrhiza have resulted in researchers pointing to AMF as critical to the development of sustainable agricultural systems (Douds et al. 1997; Rabatin and Stinner 1989; Hamel 2004; Plenchette et al. 2005).

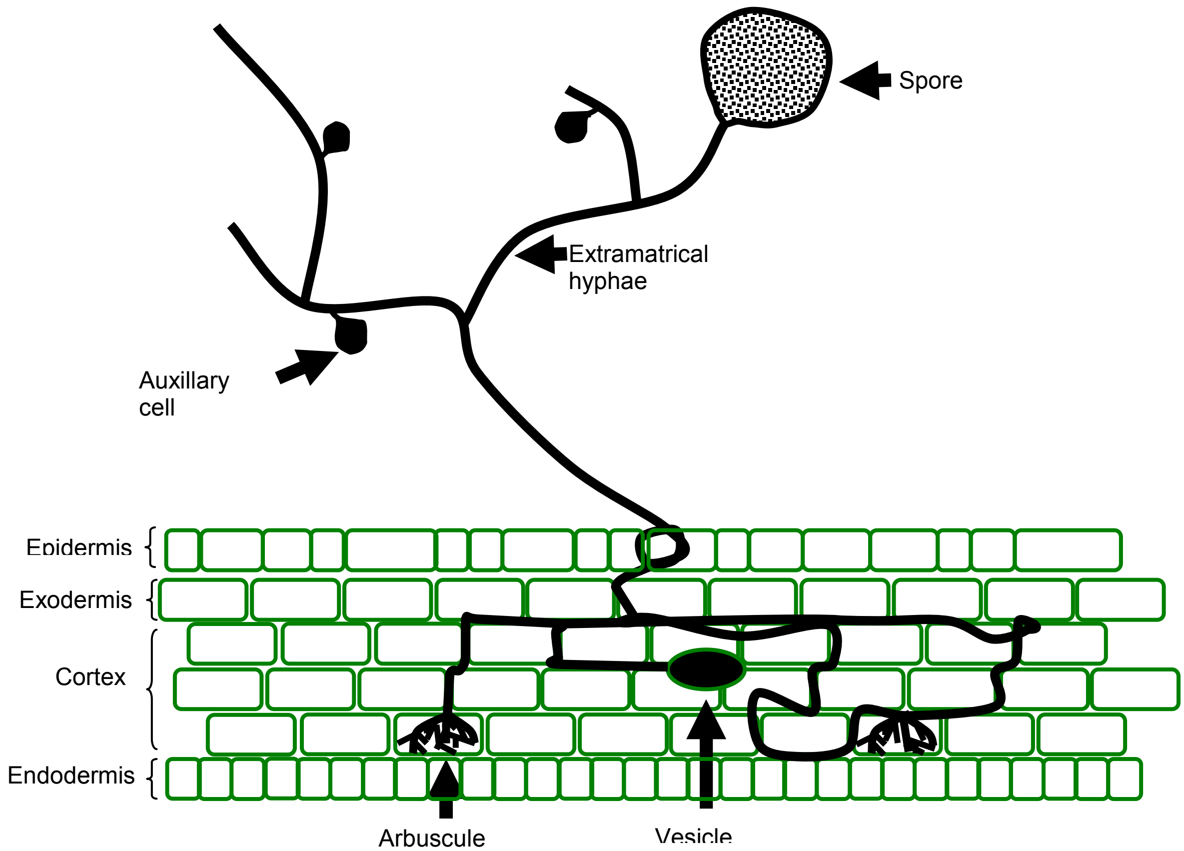
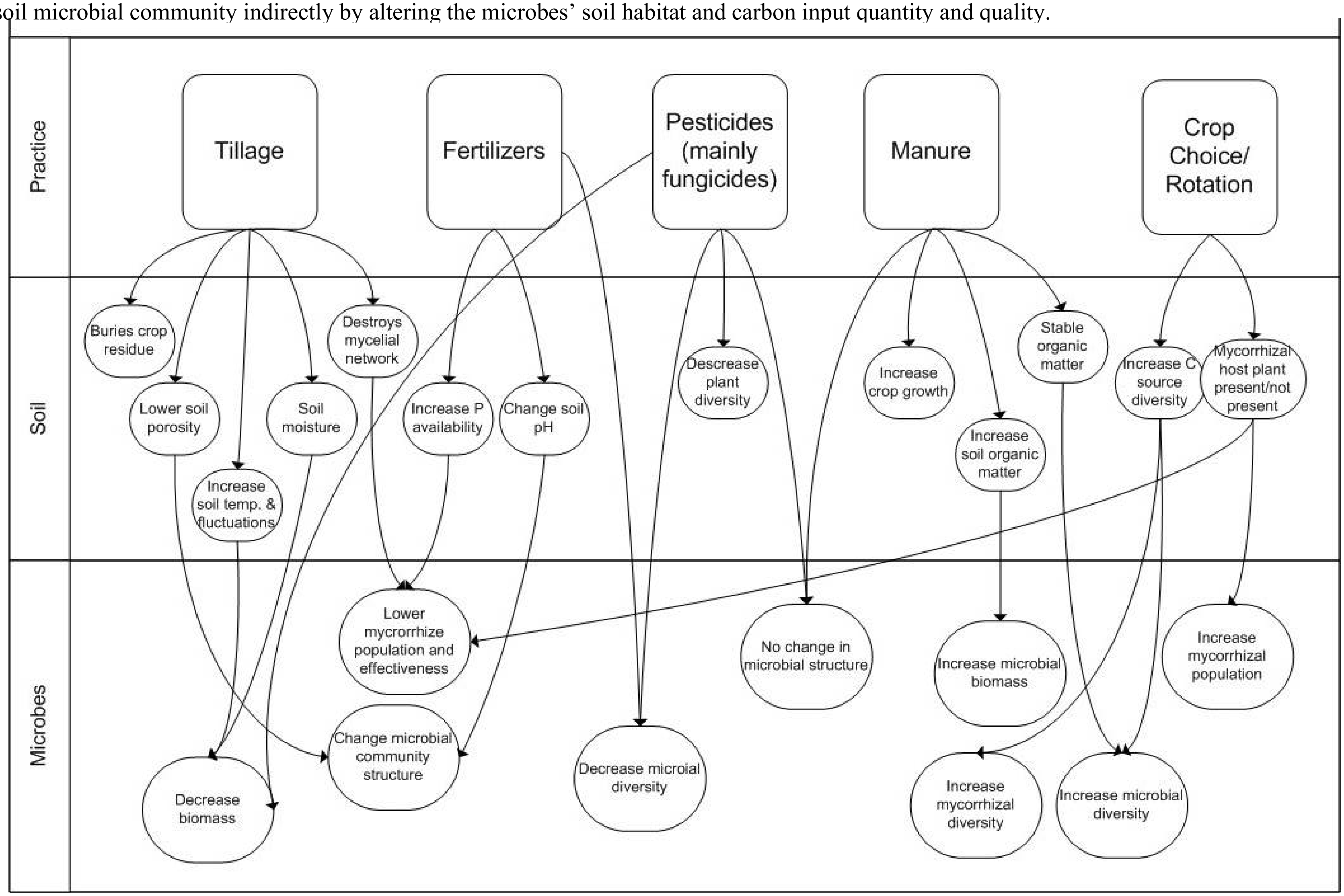


Figure 1-2. An example of an arbuscular mycorrhizal fungi association with a plant root showing some of the typical structures present. Arbuscules form within the apoplastic space of root cortical cells and are believed to be the site of nutrient exchange between the fungi and plant. Vesicles can form in some species/strains of mycorrhizae, their function is not fully known, but is believed to have a role in storage. Extramatrical hyphae (hyphae extending beyond the root) take up nutrients from the soil. Hyphae can access areas beyond the root depletion zone for some nutrients (hyphae can go about 10mm beyond the root – the P depletion zone is about 1mm around the root). Spores are structures of asexual reproduction. Auxillary cells can also be found on the extramatrical hyphae, their positioning on the hyphae and their shape are species/strain dependent.

1.4 Management Practices Affecting Soil Microbiological Diversity

Soil microbes need water, energy (in the form of soil organic matter or plant and animal residues), and essential elements from the soil solution, soil minerals or soil atmosphere. Physically, the critical controlling factors of microbial diversity are: soil organic matter content, the composition of the mineral fraction, and the relative proportions of air and water (Thies and Grossman 2006). Chemically, important factors affecting microbial diversity are: pH, cation- and anion-exchange capacity, mineral content and solubility, buffering capacity, concentration of nutrient elements in the soil, concentration of gases; e.g. oxygen, carbon dioxide, in the soil, soil water content, and salinity or sodicity (Thies and Grossman 2006). While management practices can alter microbial communities directly, for the most part, management practices change microbial communities indirectly by altering a number of the above-named soil properties affecting microbial diversity. Because most microbes are heterotrophic, soil organic matter content and the type and amount of organic materials added to the soil are two critical soil factors affecting microbial diversity (Shannon et al. 2002). Some management practices that have been studied for their effect on soil microbial communities are tillage, crop choice and rotation practices and soil amendments and pesticides (Figure 1-3).

Figure 1-3 Flow chart of the reviewed management practices and their impact on the soil microbial community. Management practices generally affect the soil microbial community indirectly by altering the microbes' soil habitat and carbon input quantity and quality.



1.4.1 Tillage

Tillage has negative effects on soil structure, breaking aggregates, compacting the soil, and adversely affecting pore size distribution and structure (Huwe and Titi 2003). Tillage also buries crop residue and changes soil water and temperature regimes (Kladivko 2001). In general, lower tillage intensities will have a positive effect on soil microbial communities. Zero tillage systems are characterized as having increased soil moisture and fewer fluctuations in soil temperature than conventional tillage systems, thereby increasing soil microbial populations (Kladivko 2001). Tillage alters the soil microbial community structure, both immediately following, and with increasing time after a tillage event (Calderón et al. 2000; Jackson et al. 2003). Changes in microbial communities due to tillage can be measured 7 years following the cessation of cultivation, because microbes respond to soil conditions that take a long time to change following disturbance (Buckley and Schmidt 2001 and 2003). Increased tillage intensities alter microbial community composition and substrate utilization (Cookson et al. 2008). In Alberta, Canada, tillage was found to decrease soil microbial diversity and evenness (Lupwayi et al. 1998). Microbial activity also decreases with increasing tillage intensity. In comparing zero-till, organic, low-input, continuous corn and grassland systems, soil metabolic activity and nitrogen mineralization was highest in systems of minimal tillage (the zero-till and grassland systems) (Weil et al. 1993). Tillage disturbs the soil biotic community, possibly having a negative effect on the efficiency of nutrient cycling (Werner and Dindal 1990).

Tillage intensity has a large effect on the fungal fraction of the soil microbial community. It is generally believed that zero tillage systems are fungal dominated, while conventional tillage systems are bacterial dominated (Kladivko 2001). Tillage decreases the fungal component of a soil microbial community for at least two weeks following an operation (Jackson et al. 2003). Tillage negatively affects mycorrhiza populations. Mycorrhizal colonization potential of the soil is related more to the presence of fungal hyphae and colonized root pieces than to spore populations (Douds et al. 1997). Thus, tillage has a direct effect on mycorrhizal colonization, as tillage destroys the mycelial network within the soil (Evans and Miller 1990; Boddington and Dodd 2000). Conventional tillage systems have lower levels of mycorrhizal survival and proliferation than zero tillage systems, thereby reducing the benefits of mycorrhizal associations to plants and soils (Kabir 2005). Tillage can also have negative effects on the sporulation of some AMF species and the distribution of spores through the soil profile (Jansa et al. 2002; Rabatin and Stinner 1989; Abbott and Robson 1991; Boddington and Dodd 2000). In addition to reducing mycorrhiza abundance, differences in mycorrhiza community structure due to tillage system (conventional vs. zero) have been observed (Jansa et al. 2002). The reduction in mycorrhiza populations by tillage has been linked to reduced P absorption in crops (Abbott and Robson 1991; Evans and Miller 1990).

1.4.2 Crop Choice and Rotation

Most soil microbes are heterotrophic and thus the type and amount of organic materials added to the soil has a significant impact on microbial community structure (Shannon et al. 2002). Crop rotation is one of the most important tools available to farmers to manage agronomic issues (von Fragstein und Niemsdorff and Kristiansen 2006). Differential effects of plant species on soil microbial communities may be caused by differences in plant material composition and differences in plant root exudates. Root exudates are influenced by environmental and plant factors, including the nutritional status of the plant, so the influences of plant root exudates on microbial communities may be site- and time-specific (Grayston et al. 1998; Koo et al. 2006). Greater numbers of crops grown over time (e.g. less fallow), and greater diversity of crops can positively affect microbial communities.

Different field crops may or may not have differing effects on soil microbial community and diversity. The rhizosphere of monocropped wheat (*Triticum aestivum* L.) had more bacteria and fungi present than the rhizospheres of forage species such as ryegrass (*Lolium perenne* L.) or bentgrass (*Agrostis capillaries* L.) (Grayston et al. 1998). The differences in the microbial communities of various plant rhizospheres led to differences in carbon source utilization patterns, indicating that plant species affected microbial functional diversity (Grayston et al. 1998). Other studies have reported little to no difference amongst the rhizospheres of various crop species. Microbial diversity has been reported to be similar under wheat, maize (*Zea mays* L.) and faba bean (*Vicia faba* L.) (Song et al. 2007). Of the bacteria associated with red clover (*Trifolium pretense* L.) and potato (*Solanum tuberosum* L.), 73% were of the same species (Sturz et al. 1998).

Crop species may or may not have differential effects on soil microbial communities, depending on environmental and plant factors. However, soil microbial diversity does increase with increased above-ground plant diversity both spatially and temporally (Garbeva et al. 2006). Intercropping can increase microbial diversity when compared with crops grown in monoculture (Song et al. 2007). Increasing rotational diversity can also increase microbial diversity. A legume green manure-wheat rotation exhibited greater microbial diversity than continuous wheat (Lupwayi et al. 1998). By replacing the tilled fallow phase of a fallow-wheat rotation with green legume fallow, Biederbeck et al. (2005) reported increased soil microbial community biomass, carbon, nitrogen and microbial community, due to an increase in soil organic matter.

Genetic differences within a crop species also play a role in the structure of the microbial community. Differences have been found in microbial communities associated with different wheat and canola (*Brassica napus* L.) cultivars (Siciliano et al. 1998; Germida and Siciliano 2001). The microbial community structure associated with the wheat cultivar Cadet was altered when a pair of homoeologous chromosomes conferring root rot resistance was substituted from the wheat variety Rescue to Cadet (Neal et al. 1972).

Crop cultivars that have been developed through genetic engineering can have a temporary impact on microbial diversity and community structure that lasts the lifecycle of the plant (Dunfield and Germida 2003 and 2004). Plants with transgenes affect soil microbes directly by releasing transgene proteins into the environment as well as indirectly through a change in root exudates (Liu et al. 2005). Lower diversity, or altered structure, in the community of bacteria within the roots of transgenic, glyphosate-tolerant canola cultivars versus non-transgenic or other herbicide-tolerant transgenic cultivars has been reported (Siciliano and Germida 1999). While genetically engineered crops do affect the soil microbial community, these effects (being temporary and dependent on the type of transgene) are likely not as important in comparison to the effect of other management practices like rotation, tillage and chemical use (Dunfield and Germida 2004).

Crop species and varietal selection can also greatly affect mycorrhiza populations. Plant species from the *Chenopodiaceae* and *Brassicaceae* families, including the western Canadian canola species *Brassica napus* L. and *Brassica rapa* L., are generally not colonized by mycorrhiza (Plenchette et al. 1983). About 80% of all plants form mycorrhizal symbiosis, although some species are more dependent on mycorrhiza than others. Mycorrhizal dependency is measured as the percent increase in growth of a plant when colonized by mycorrhiza. Field crops have an average mycorrhizal dependency of 44%, compared to 70% for wild plant species, with a large degree of variation between species within these averages (Tawaraya 2003). Legume species have mycorrhizal dependency values of around 90%, maize has a medium mycorrhizal dependency of about 50%, while modern wheat, oat (*Avena sativa* L.), rye (*Secale cereale* L.) and barley (*Hordeum vulgare* L.) varieties are considered weakly dependent, with values between -13% to 50% (Plenchette et al. 1983; Hetrick et al. 1992; Mosse 1986; Tawaraya 2003). While examining modern wheat cultivars and their ancestors, researchers concluded that mycorrhizal dependency is being bred out of modern wheat varieties, and is a challenge to the optimization of mycorrhizal in cropping systems (Hetrick et al. 1993; Rillig 2004). To successfully manage mycorrhiza populations in agricultural systems there needs to be crop breeding aimed at 'mycorrhizal effectiveness' (Hamel 2004). Mycorrhiza can improve plant nutrient status in lower soil nutrient levels, providing benefits to organic and conventional systems, by lowering the fertility input requirements. The loss of mycorrhizal dependency would mean the loss of an important natural advantage to agricultural systems.

Crop rotation plays a large role in determining the mycorrhiza population in the soil and colonization potential. A diversity of host plants can increase the diversity of the mycorrhiza population and increase colonization levels (Rabatin and Stinner 1989; Sattelmacher et al. 1991). Non-mycorrhizal plants in rotation have lower soil mycorrhiza spore populations than mycorrhizal plants, thus lowering the infectivity of the soil in the subsequent year (Douds et al. 1997). Conversely, the presence of a host plant species helps maintain the mycorrhizal inoculum potential of a soil (Kabir 2005; Kabir and Koide 2000). Some crops tend to encourage a larger mycorrhizal community, with greater species richness (Douds and Millner 1999). An overwintering cover crop can maintain AMF populations when no crop is present. Mycorrhizal colonization potential was higher in soil with a hairy vetch (*Vicia villosa* Roth) winter cover crop than in soil without a cover crop (Galvez et al. 1995). The host plant species can also affect mycorrhizal diversity, with greatest diversity under soybean (*Glycine max* L.) or sunflower (*Helianthus annuus* L.) (Jansa et al. 2002). The specificity of some mycorrhiza to certain crop species in rotation may influence the diversity and infectivity of the mycorrhiza populations in the following crop (Hamel and Strullu 2006).

1.4.3 Chemical Inputs

Agriculture is essentially an extractive system. Nutrients are taken out of fields and exported in the form of grain, crop biomass and/or animal protein. At some point, nutrients must be added back to both organic and conventional systems to ensure their sustainability. In conventional systems, this mainly takes the form of inorganic fertilizers, while in organic systems fertility inputs include manures and composts, nitrogen derived through legume biological fixation and mined mineral sources of phosphorus and some micronutrients. The effect of inorganic and organic fertility amendments on soil microbes has been studied by some researchers.

The addition of manure to a soil increases microbial biomass, and may alter the community structure of soil microbes by increasing soil organic carbon (Frostegård et al. 1997; Fauci and Dick 1994). The type of substrate added (e.g. compost versus fresh plant material) may or may not affect community structure (Drenovsky et al. 2004; Fauci and Dick 1994). The handling of manure prior to application also appears to have an effect. Biodynamic agricultural systems are a form of organic farming that includes metaphysical and spiritual aspects, and prescribes specific compost treatments to be applied to the soil at specific calendar dates. Fließbach and Mäder (2000) reported that microbial communities supplied with biodynamically composted manure had a lower metabolic quotient (µg CO_2-C mg C_{mic} h^{-1}) than those supplied uncomposted manure. Comparing traditionally and biodynamically composted manure, soil biological activity was similar but metabolic quotient higher in biodynamic treatments. Thus researchers hypothesized that biodynamic compost treatments received more stabilized organic matter and had a more diverse microbial community (Zaller and Köpke 2004). The reasons for the greater performance of biodynamic composts are unclear.

Inorganic fertilizers, in comparison to manures and composts, do not directly add organic carbon to the soil, but can alter soil chemistry, specifically soil pH, thereby changing soil microbial habitats (Bünemann et al. 2006; O'Donnell et al. 2001). Soil treated with inorganic fertilizers tends to have lower microbial biomass, as well as a different community structure than soil treated with organic fertility amendements, such as manures or composts (Marschner et al. 2003; O'Donnell et al. 2001; Peacock et al. 2001; Seghers et al. 2003; Suzuki et al. 2005). Up to 10 days following fertility input, there can be a change in community structure; however, these effects generally disappear by 91 days after application (Stark et al. 2007). Following long-term application of organic and inorganic fertilizers, researchers reported an increase in the amount of bacteria present (Marschner et al. 2003). However, this change in structure was not accompanied by a change in enzyme activity, indicating that ecosystem functioning was not affected by this change in structure. Inorganic fertilizers can also alter microbial communities indirectly through increased plant production. In some cases, the impact of inorganic fertilizers, and the change in soil pH has a greater effect on soil microbial community, than organic fertilizers, which tend to increase soil organic matter (Suzuki et al. 2005). An extreme case of an agricultural field polluted by inorganic fertilizers had higher organic carbon, total nitrogen and C/N ratio, but lower diversity and richness of microbial DNA sequences than fields with no, or normal agrichemical use (Yang et al. 2000).

The application of phosphorus fertilizers can have a positive, neutral, or negative effect on mycorrhizal colonization (Manske 1990; Abbott and Robson 1991; Rabatin and Stinner 1989). The negative effect of phosphorus fertilizers on mycorrhiza populations has been attributed to increased soil levels of available phosphorus (Hamel and Strullu 2006). With high levels of phosphorus, root cell membranes are more stable, reducing root exudates, thereby reducing colonization levels (Habte 2006; Mosse 1986). Lower mycorrhizal colonization levels in wheat have been attributed to the application of superphosphate, a soluble P fertilizer (Ryan et al. 2004).

As well as decreasing mycorrhizal colonization, high levels of available nutrients serve to decrease the relative benefits of mycorrhiza and can actually decrease plant productivity (Aikio and Ruotsalainen 2002; Ryan and Graham 2002; Stewart et al. 2005). The mycorrhizal demand for crop carbon may actually decrease yields in some conventional, high fertility environments (Ryan and Graham 2002). The relationship between higher phosphorus levels and lower mycorrhizal colonization is specific to plant species and cultivars (Habte 2006). Roughly half of 44 spring wheat varieties grown under high phosphorus conditions exhibited parasitic effects of AMF inoculation, with lower shoot dry weight in inoculated plants (Manske 1990).

Results are less clear when comparing organic and inorganic fertility inputs. Clay soil treated with manure had higher levels of active hyphae than soils treated with inorganic fertilizers (Kabir et al. 1997). Another study reported AMF colonization to be greater under composted manure versus raw manure or inorganic fertilizer (Douds et al. 1997). Mycorrhizal infection was found to decrease with increasing amounts of manure inputs; as well as a smaller mycorrhizal effect on plants when using sterile versus unsterile manure (Brechelt 1990). The decreased effects of mycorrhiza with increasing amounts of applied manure were attributed to greater nutrient availability.

Conventional systems rely (at least in part) on synthetic pesticides to control weed, disease and insect problems in the field. The impact of pesticides on microbial population biomass has been studied, and, in general, when pesticides are applied at recommended rates, there is little to no impact on microbial populations (Fraser et al. 1988; Seghers et al. 2005; Shannon et al. 2002). However, Johnsen et al. (2001) suggested that insufficient studies have been conducted to assess the effect of pesticide use on microbial diversity. We do know that some pesticides can have a harmful effect on soil microbes, but which pesticides, and the long-term impact of changes to the soil community because of those pesticides is unknown (Bünemann et al. 2006). Herbicides have little effect on the soil community, while some insecticides and fungicides had negative effects on soil microbes (Bünemann et al. 2006). In a case of field scale pesticide pollution, microbial biomass declined on fields with normal application rates, but pesticide pollution did not appear to alter the diversity of the microbial population (Yang et al. 2000). However, because plant diversity affects soil microbial diversity (discussed in previous section), the use of herbicides may indirectly affect microbial diversity by killing weeds and reducing plant species diversity.

Pesticides can have a negative effect on mycorrhizal communities, lowering colonization and sporulation of certain species; however, these effects seem to be temporary (Gosling et al. 2006). The use of the herbicide diclofop lowered dry weights of wheat inoculated with AMF, possibly due to a decline in colonization (Rejon et al. 1997). Another study reported that AMF colonization levels were not affected by herbicides (Ryan et al. 1994). At recommended rates, most herbicides do not appear to alter mycorrhizal communities (Mosse 1986). Some fungicides can lower mycorrhizal numbers, by directly affecting the fungi (Bünemann et al. 2006). Herbicides may reduce mycorrhizal numbers through a reduction of host weeds (Gosling et al. 2006).

1.5 Organic and Conventional Cropping Systems

The preceding sections examined the effects of management practices individually (see Figure 1-1). Cropping system comparisons present challenges as reductionist science, because many factors must vary in order to ensure proper functioning of the respective systems (Lampkin et al. 1994). Organic and conventional systems are not defined by a set group of practices; they are an aggregate of a number of management practices dictated by farmer choice and site-specific requirements, rendering generalizations about on cropping systems quite difficult (Harrier and Watson 2003). This implies there is no clear definition of the two separate systems, but rather a spectrum of systems, into which all farms would fall (Lampkin et al. 1994). The International Federation of Organic Movements defines organic agriculture as “a production system that sustains the health of soils, ecosystems and people. It relies on ecological processes, biodiversity and cycles adapted to local conditions, rather than the use of inputs with adverse effects. Organic agriculture combines tradition, innovation and science to benefit the shared environment and promote fair relationships and a good quality of life for all involved.” (International Federation of Organic Agriculture Movements 2008). At its most basic, and common to all organic agricultural systems, it is defined by the absence of synthetic pesticides and fertilizers. For this paper, we consider conventional cropping systems to be all systems of production not including biodynamic and organic. Despite the difficulties in studying and comparing organic and conventional cropping systems, there is value in such studies. Both organic and conventional cropping systems consist of a number of different management practices (chemical use, tillage, crop rotation and crop choice) used in combination. Despite the ranges of management practices used on organic and conventional cropping systems, there are a number of factors which are commonly found to differ between the two systems.

Organic systems tend to have higher organic matter, more weeds, lower yields and lower phosphorus levels than conventional systems (Entz et al. 2001; Pimentel et al. 2005; Martin et al. 2007; Roberts et al. 2008). The absence of inorganic fertilizers and pesticides in organic systems generally leads to greater weed populations, higher tillage intensities, and lower soil nutrient levels. As well, organic systems often have more diverse crop rotations and higher plant diversity within fields than conventional systems. Soil organic matter is an important determinant of microbial populations, serving as a source of energy for microbes, and ultimately an important pool of nitrogen, phosphorus and sulphur (Stockdale et al. 2002). Organic systems employ a number of practices that serve to increase organic matter content, generally resulting in slightly higher levels of organic matter in organic systems versus conventional systems (Bossio et al. 1998; Drinkwater et al. 1995; Shepherd et al. 2002). Organic management exhibited greater or equal soil organic carbon levels compared to conventional management in long-term studies (Wander et al. 1994; Fließbach and Mäder 2000; Teasdale et al. 2007). In some cases, organic management has resulted in lower organic matter contents than conventional management (Girvan et al. 2003; Stark et al. 2004). This may be due to lower yields in organic systems returning lower levels of organic matter to the soil. In the case of extensive dryland cropping systems in western Canada that tend to rely on tillage for weed control, it is suspected that these organic systems would have similar, or lower organic matter and organic carbon levels to their conventional counterparts, depending on the added use of green manures.

1.6 Cropping Systems Management and Microbial Communities

With greater organic matter to provide an energy source for microbes, it is not surprising that a number of studies have reported higher microbial biomass in organic systems than conventional systems (Fließbach et al. 1997; Hole et al. 2005; Mäder et al. 2002; Fließbach and Mäder 2000; Wander et al. 1995). The diversity and structure of soil microbial communities is also important in these systems. Some studies have reported shifts in microbial communities with organic versus conventional management, while others have reported no differences between microbial communities under the two management systems (Bossio et al. 1998; Yeates et al. 1997; Girvan et al. 2003; Wander et al. 1995; Lundquist et al. 1999). The absence of differences in some studies has been attributed to the greater effects of soil type and time of sampling (Bossio et al. 1998; Girvan et al. 2003; Stark et al. 2004; Wander et al. 1995). A comparison of organic and conventional pastures reported no difference in soil biological diversity (Parfitt et al. 2005). In this case, the similarity between the two systems may be due to a lack of sufficient management differences, with only fertility regime differing. Additionally, perennial intercrops may have exhibited a greater effect on microbial diversity than the fertility inputs. Differences in soil microbial community structure between organic and conventional systems is not necessarily negative, but indicative that these systems have very different soil conditions and perhaps require different functions from the soil microbes. While studying the effect of moisture stress on organic and conventional soils, Lundquist et al. (1999) reported different community structure in the two soils, but no differences in community response to stress. However, if we are to strive towards a reduced dependence on inorganic fertilizers, we must ensure that the soil microbial community can carry out functional requirements to recycle nutrients efficiently.

Mycorrhizal potential, and actual colonization has been reported to be greater in grasslands, organic and low-input systems versus conventional systems (Eason et al. 1999; Entz et al. 2004; Galvez et al. 1995; Mäder et al. 2002; Mäder et al. 2000; Oehl et al. 2003; Oehl et al. 2004; Sattelmacher et al. 1991; Scullion et al. 1998). This is in large part due to the fact that the application of phosphorus fertilizers, even at low rates, decrease root colonization of mycorrhiza (Clapperton et al. 1997; Mäder et al. 2000; Ryan et al. 1994; Ryan et al. 2004). Differential mycorrhizal community structure has been reported, with organic systems maintaining community structures similar to natural systems. Conventional systems tend to have lower species richness, with the associated risk of lower mycorrhizal functioning (Oehl et al. 2003; Oehl et al. 2004). Exceptions, of course, have been reported. No differences were reported in diversity of soil fungal communities in organic and conventional systems in Florida (Wu et al. 2007). Eason et al. (1999) reported the percent mycorrhizal infection of roots was one-third greater on organic farms than conventional farms, however, there was a great deal of variation in management practices between the farms, and therefore a great deal of variation in the mycorrhizal infection rates amongst farms (Eason et al. 1999).

Mycorrhizal host plants need not be crop plants. Weeds may host mycorrhiza during rotation phases with non-host crops or during the over-wintering period. The presence of weeds may also have a positive effect on soil processes, through the addition of plant residues and root exudates (Werner and Dindal 1990). Weeds present during the crop season may also provide greater plant diversity for the mycorrhiza, as plant diversity is usually positively correlated to a diversity of AMF (Douds et al. 1997; Rabatin and Stinner 1989). Mycorrhizal weed species can increase mycorrhizal diversity and abundance, as well as influence community structure, improving the mycorrhizal potential of soil (Vatovec et al. 2005). (Table 1-1 provides a list of some mycorrhizal and non-mycorrhizal weed species.) One field study maintaining dandelions (*Taraxacum officinale* Weber ex Wigg) as a winter cover crop reported the weed provided mycorrhizal inoculum potential for a subsequent maize crop, increasing mycorrhizal colonization and phosphorus concentration of the maize (Kabir and Koide 2000). Wheat grown in the presence of a non-mycorrhizal weed, *Chenopodium album*, experienced lowered levels of mycorrhizal colonization, while maize experienced an increase in colonization (Stejskalova 1990). Mycorrhizal colonization can also increase or decrease the growth of weeds in the field, depending on the soil and species (Vatovec et al. 2005). The presence of mycorrhiza can change the composition of weed communities, selecting for host species. Conversely, the weed community can alter mycorrhiza communities, with diverse weed hosts encouraging increased mycorrhizal diversity (Jordan et al. 2000). Soil taken from fields under organic, transitioning to organic and conventional management had similar mycorrhizal colonization levels of various weed species (Vatovec et al. 2005). The presence of weeds within a crop lowers crop productivity. However, it appears that organic fields may derive some benefits from weed pressure that is ubiquitous within these systems.

Table 1-1. Summary of mycorrhizal colonization ability of various weed species.[z]

Mycorrhizal or non-mycorrhizal?	**Common Name**	**Family**	**Species**
Mycorrhizal	Ragweed	*Asteraceae*	*Ambrosia artemisifolia*
Mycorrhizal	Canada thistle	*Asteraceae*	*Cirsium arvense*
Mycorrhizal	Dandelion	*Asteraceae*	*Taraxacum officinale*[y]
Mycorrhizal	Cocklebur	*Asteraceae*	*Xanthium strumarium*
Mycorrhizal	Velvetleaf	*Malvaceae*	*Abutilon theophrasti*
Mycorrhizal	Quackgrass	*Poaceae*	*Agropyron repens*
Mycorrhizal	Giant foxtail	*Poaceae*	*Setaria faberi*
Mycorrhizal	Yellow foxtail	*Poaceae*	*Setaria lutescens*
Mycorrhizal	Nightshade	*Solanaceae*	*Solanum nigrum*
Non-mycorrhizal	Pigweed	*Amaranthaceae*	*Amaranthus retroflexus*
Non-mycorrhizal	Mustard	*Brassicaceae*	*Brassica kaber*
Non-mycorrhizal	Lambsquarters	*Chenopodiaceae*	*Chenopodium album*
Non-mycorrhizal	Smartweed	*Polygonaceae*	*Polygonum lapathifolium*
Non-mycorrhizal	Purslane	*Polygonaceae*	*Portulaca oleracea*
Non-mycorrhizal	Curly dock	*Polygonaceae*	*Rumex crispus*

[z] Adapted from Vatovec et al. (2005), source is Vatovec et al. (2005) unless otherwise specified.

[y] Source: (Kabir and Koide 2000)

1.7 Interactions and the Relative Importance of Management Practices

Rotation and tillage practices interact to alter microbial communities, with previous crop effects greater under zero tillage management (Lupwayi et al. 1998). Tillage may have a greater effect on soil microbial populations than herbicides (Table 1-2). In a study comparing zero and conventional tillage systems, researchers reported that any effect of increased herbicide use on microbial diversity in a zero tillage system was overridden by the greater effects of tillage (Lupwayi et al. 1998). Other researchers concluded that fertilizers can affect microbial populations more than pesticides (Yang et al. 2000). The use of transgenic crops in rotation was concluded to be less important to microbial community structure than rotation, tillage or chemical use (Dunfield and Germida 2004). Still others have suggested that long-term management histories have a greater effect on microbial communities than current practices and crop selection (Buckley and Schmidt 2003). Similarily, it was reported that soil and environmental factors had a greater effect on microbial structure than short-term management practices such as fertility inputs (Stark et al. 2007; Wakelin et al. 2008). An Australian study reported that soil pH was the most important soil characteristic when determining microbial community diversity and function (Wakelin et al. 2008).

While tillage is important in determining mycorrhiza abundance and diversity, other management practices play important roles. Studies have reported host plant species (and threrfore crop rotation) to have a greater effect on mycorrhizal diversity, and cropping system (organic versus conventional) to have a greater effect on mycorrhizal abundance than tillage (Galvez et al. 2001; Jansa et al. 2002). The greater effect of cropping system on mycorrhizal colonization is most likely due to differences in soil phosphorus levels. However, rotation phase has been reported to have a greater effect on infection potential of the mycorrhizal population than the fertility amendment used, indicating that crop rotation complexity may affect differences mycorrhizal colonization levels in organic and conventional systems (Douds et al. 1997).

Site-specific factors play a role in the relative importance of management practices on soil microbial communities, as well as how management practices will impact soil microbes. In general, farming practices that sustain or create soil conditions that are optimal for plant growth will also encourage abundant and diverse soil microbial communities (Thies and Grossman 2006). While site-specific characteristics are important in determining the structure of the soil biological community and how management practices affect that biological community, the general principles of managing for a productive, sustainable system remain the same across ecosystems (Uphoff et al. 2006).

Table 1-2. Summary of the management practices and their relative impact on the soil microbial community and mycorrhizal community.

<table>
<tr><th></th><th colspan="2">Effect of Management Practice on:</th></tr>
<tr><th>Management Practices</th><th>Microbial community</th><th>Mycorrhizal community</th></tr>
<tr><td>Tillage</td><td></td><td></td></tr>
<tr><td>Reduced tillage</td><td colspan="2">Positive[z]</td></tr>
<tr><td>Heavy tillage</td><td colspan="2">Negative</td></tr>
<tr><td>Rotation</td><td></td><td></td></tr>
<tr><td>Diverse rotation</td><td colspan="2">Positive</td></tr>
<tr><td>Intercrops</td><td colspan="2">Positive</td></tr>
<tr><td>Fallow in rotation</td><td colspan="2">Negative</td></tr>
<tr><td>Non-mycorrhizal crop in rotation</td><td>?</td><td>Negative</td></tr>
<tr><td>Transgenic crop in rotation</td><td>Negative</td><td>?</td></tr>
<tr><td>Crop inputs</td><td></td><td></td></tr>
<tr><td>Organic fertility amendments</td><td colspan="2">Positive</td></tr>
<tr><td>Inorganic fertility amendements</td><td colspan="2">Positive or Negative (depends on fertilizer effects, organic matter inputs to soil, soil pH, etc.)</td></tr>
<tr><td>Fungicides</td><td>Negative</td><td>Negative</td></tr>
<tr><td>Insecticides</td><td colspan="2">Negative</td></tr>
<tr><td>Herbicides</td><td colspan="2">Negative</td></tr>
</table>

[z]Items in bold indicate that the management practice has a large effect on the community in question. Items not bolded have a small effect on the community.

1.8 The Management of Soil Biological Fertility

While certain organisms or functional groups play specific roles in soil nutrient cycling (e.g. Rhizobia bacteria fixing atmospheric nitrogen into ammonia), it is likely impossible to manage the agricultural soil system specifically for all the beneficial organisms and functions desired. It is estimated that, at most, 5% of the soil microorganisms have been identified and their role studied (Anderson 2003; Uphoff et al. 2006). Because the environmental control of soil nutrient release is complicated and because we have a limited ability to predict soil processes, manipulating individual microbial processes affecting soil fertility is not a viable option (De Neve et al. 2004;

Robertson and Grandy 2006; Watson et al. 2002). Realistic management strategies to improve biological nutrient cycling must rely on well-established knowledge. To improve biological nutrient cycling, cropping systems can be managed to ensure diverse microbial communities and abundant mycorrhizal populations.

Maintaining soil biological diversity is important to maintain the integrity of the functioning of the soil system. There is some functional redundancy in soil systems; however, our limited understanding of microbial systems, makes any theory about functional redundancy speculatory (Anderson 2003; Kennedy and Smith 1995). Lowered soil microbial diversity, or a change in soil community structure within an agroecosystem may not have negative impacts on soil biological fertility. However, despite our incomplete understanding of the connections between microbial diversity, ecosystem functioning and functional redundancy, we do know that at some point in the loss of soil microbial biodiversity there will be a loss of function (Coleman et al. 1994). Diversity in the soil microbial community should be maintained to ensure nutrient cycles and other soil functions continue.

In organic systems, there is already effort expended on improving soil fertility through the creation of diverse soil microbial communities, because these systems rely on biological fertility for the production of crops (Davis and Abbott 2006). Organic systems, with manure, compost or green manure fertility inputs, low (or no) fertilizer and pesticide inputs and diverse plant communities, seem fairly well-designed to encourage a healthy and diverse soil microbial community. However, in dryland prairie systems, with extensive farms, tillage is a large component of weed control of organic systems. Lowered tillage would improve the soil conditions for microbial diversity and mycorrhizal colonization; organic systems should strive for minimum tillage. As well, avoiding bare soil fallow in crop rotations would help to maintain the microbial community, especially the mycorrhizal component (Gosling et al. 2006).

Conventional systems represent a large range and combination of management practices, making generalizations difficult. A well-managed conventional cropping system, with minimum tillage, and low fertilizer inputs should experience similar or identical microbial diversity and mycorrhizal levels as a well-managed organic cropping system. If soil biological fertility is encouraged, through careful management, including reduced tillage, lowered fertility and pesticide inputs and diverse crop choices, conventional systems should be able to lower fertilizer rates. Lowered fertilizer inputs, especially in reduced tillage systems where mycorrhizal communities can thrive, can offset some of the negative impacts of high input systems. Both organic and conventional systems should begin to incorporate intercrops into rotations. Above-ground diversity, spatially and temporally, is very important in determining below-ground diversity.

1.9 Conclusion

The impact of production practices on soil microbial diversity and mycorrhizal colonization has been studied to varying degrees (Vandermeer et al. 1998). This paper reviewed work in the area of crop management practices and their impact on soil microbial diversity and mycorrhizal communities. We have not reached a point where definitive relationships between production practices and microbial community structure can be defined. All of the management practices discussed in this paper have aspects of site-specificity in their effect on microbial communities, making broad generalizations about the effect of a particular practice on microbial structure difficult. Knowing the ecological principles guiding microbial community structure can help farm managers tailor their cropping practices to a particular set of conditions. In general, lowered fertilizer and pesticide use, diverse crop rotations that include mycorrhizal plant species, reduced tillage systems as well as the use of intercrops and cover crops can maintain or improve indigenous mycorrhizal communities and microbial diversity (Plenchette et al. 2005; Thies and Grossman 2006). Organic cropping systems should strive for minimum tillage systems while conventional systems should work towards lowered reliance on fertilizers to supply crop nutrients. Both organic and conventional cropping systems should begin to grow intercrops to encourage diversity within the soil system.

1.10 Objectives

Increased interest in the nutritional quality of food products and the environmental impact of cropping system practices has, in part, lead to increased organic agricultural production in Canada. The number of farms producing certified organic products increased by 59% from 2001 to 2006 (Statistics Canada 2008). Despite the increased demand for, and production of organic food products, organic certification guarantees the process used to produce the good, not the final product characteristics. Information on the impact of specific management practices is needed to develop systems that produce high quality food products in both organic and conventional management regimes. Soil microbes play important roles in soil functioning within ecosystems, yet research into the impacts of management practices on soil microbial communities in Canada is limited, and often does not include organic cropping systems. While protein is a standard parameter in wheat breeding, nutrient content of wheat has not been a traditional breeding objective and identification of cultivars with increased nutrient content would assist breeders in developing nutritionally superior wheat cultivars. Little research has been carried out on complex (three- or four-crop) annual intercropping systems in the Canadian prairies, and none exist on organic systems in western Canada. Looking at a common production practice of cultivar choice, and the novel production practice of intercropping will help begin to understand how soil microbial communities and crop quality under organic and conventional management systems react to cropping practices.

The objectives of the present thesis research were to:

1. Determine the effect of organic and conventional management and spring wheat cultivar choice on soil microbial communities, crop productivity, and breadmaking quality in central Alberta.
2. Compare the concentrations of seven minerals, including Se, Cu, Mn, Zn, Fe, Mg and K in a subset of hard spring wheat cultivars grown over the last 100 years in western Canada in both conventional and organic environments.
3. Explore the effect of the microbial community structure in organic and conventional management systems on micronutrient content.
4. Compare monoculture of spring wheat, barley, canola and peas, along with all 2-, 3- and 4-crop intercrop combinations with wheat for productivity and weed suppression under both organic and conventional management systems.
5. Determine effect of intercrops of common annual crops grown on the Canadian prairies on soil microbial communities under organic and conventional management systems.

The underlying null hypotheses tested were:

1. Soil microbial communities, crop productivity and breadmaking quality do not differ between organic and conventional management systems.

2. Organically and conventionally grown wheat cultivars do not differ in micronutrient content. Year of release of a wheat cultivar does not have an effect on mineral content of wheat.
3. Microbial community structure does not differ between organic and conventional management systems and does not affect the micronutrient content of the wheat grown.
4. Productivity and weed suppression do not differ amongst monocrops and intercrops grown under organic and conventional management systems.
5. Intercrops have no effect on the soil microbial community under organic or conventional management systems.

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2.0 Spring wheat genotypes differentially alter soil microbial communities and wheat breadmaking quality in organic and conventional systems[2]

2.1 Introduction

A well-functioning soil requires, in part, a diverse community of soil organisms to cycle nutrients, impart resistance and resilience to biotic and abiotic stress and carry out other ecosystem functions (Uphoff et al. 2006; Brussaard et al. 2007). Diverse microbial communities more effectively use complex organic compounds, are more efficient carbon users, and are more able to mobilize nitrogen than less complex microbial communities (Bonkowski and Roy 2005). The relationship between soil biological diversity and ecosystem functioning has not been fully elucidated. As well, we do not know the relative importance of soil biological diversity on the integrity and sustainability of a given soil system (Welbaum et al. 2004). However, at some point in the loss of soil microbial diversity there will be a loss of ecosystem functioning. A change in microbial community structure due to disturbance can result in a reduction of soil functional stability (Griffiths et al. 2004). This means that until we know the functions carried out by specific organisms, maintaining diversity is one way of ensuring ecosystem functionality.

Soil microbes need water, energy (in the form of soil organic matter or plant and animal residues), and essential elements from the soil solution, soil minerals or soil atmosphere. Soil factors that affect microbial diversity include: soil organic matter content, the composition of the mineral fraction, the relative proportions of air and water, pH, mineral content and solubility, concentration of gases in the soil, soil water content and salinity (Thies and Grossman 2006). Management practices tend to change microbial communities indirectly by altering a number of the above-named soil properties affecting microbial diversity and directly through additions of soil organic matter. Because most microbes are heterotrophic, soil organic matter content and the type and amount of organic materials added to the soil are two critical soil factors affecting microbial diversity (Shannon et al. 2002).

Different field crops may or may not have differing effects on soil microbial community and diversity depending on environmental and plant factors. Grayston et al.

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[2] *A version of this chapter has been published. Nelson, A.G., Quideau, S., Frick, B., Niziol, D., Clapperton, J. and Spaner, D. 2011. Can. J. Plant Sci. 91: 485-495.*

(1998) reported differences in microbial functional diversity from various plant rhizospheres (annual wheat (*Triticum aestivum* L.) vs. perennial forage grasses), as indicated by differences in carbon source utilization patterns. Other studies have reported little to no difference amongst the rhizospheres of various annual and perennial crop species (Song et al. 2007; Sturz et al. 1998). However, soil microbial diversity does increase with increased above-ground plant diversity (Garbeva et al. 2006). Increasing rotational diversity can also increase microbial diversity. Wheat following a legume in rotation exhibited greater microbial diversity than wheat following wheat in northern Alberta (Lupwayi et al. 1998). Genetic differences within a crop species also play a role in the structure of the microbial community. Differences have been found in taxonomic diversity and utilization rates of substrates of microbial communities associated with different wheat cultivars (Siciliano et al. 1998; Germida and Siciliano 2001).

Inorganic fertilizers, in comparison to manures and composts, do not directly add organic carbon to the soil, but can alter soil chemistry, specifically soil pH, thereby changing soil microbial habitats (Bunemann et al. 2006). Soils treated with inorganic fertilizers tend to have lower microbial biomass, as well as a different community structure than soil treated with organic fertility amendments, such as manures or composts (Seghers et al. 2003). Some pesticides can have a harmful effect on soil microbes, but not all pesticides have been studied, and the long-term impact of changes to the soil community because of pesticides is unknown (Bunemann et al. 2006). In general, herbicides have little effect on the soil community, while some insecticides and fungicides have negative effects on soil microbes (Bunemann et al. 2006).

Canadian organic systems (which are generally extensive systems) tend to have lower yields and lower phosphorus levels than conventional systems (Entz et al. 2001). Organic systems are also generally found to have higher soil organic matter and more weeds (Pimentel et al. 2005). With greater organic matter to provide an energy source for microbes, it is not surprising that a number of studies have reported higher microbial biomass in organic systems than conventional systems (Hole et al. 2005). Some studies have reported shifts in microbial communities with organic versus conventional management (Bossio et al. 1998; Lundquist et al. 1999), while others have reported no differences between microbial communities under the two management systems (Wander et al. 1995; Girvan et al. 2003). In cases where there were no differences in microbial community from management regime, soil type and environmental factors (such as time of sampling) were reported to have a greater effect on microbial structure than short-term management practices such as fertility inputs (Girvan et al. 2003).

Grain protein content tends to increase with increasing nitrogen fertilizer application in conventional systems. Organic agriculture is dependent on organic sources of nutrients, which may or may not be as readily available to plants as nutrients from the inorganic fertilizers of conventional agricultural systems. Grain protein content has been examined in a number of studies, and there has been a trend towards lower protein in cereal grains produced organically (Bourn and Prescott 2002); although, some research has reported no differences between the systems (Mason et al. 2007b).

The objectives of the present study were to: 1) determine the effect of organic and conventional management on soil microbial communities, crop productivity, and breadmaking quality of different cultivars of spring wheat; 2) determine the effect of wheat cultivar choice on rhizosphere microbial community structure, crop productivity and breadmaking quality in organic and conventional cropping systems in central Alberta.

2.2 Materials and Methods

We grew five western Canadian spring wheat cultivars (AC Elsa, Glenlea, Marquis, Park and AC Superb) in four-replicate, randomized complete block experiments: one organically managed site and one conventionally managed site in 2005, 2006 and 2007 in Edmonton, AB (55°34´N, 113°31´W). The cultivars were chosen to represent spring wheat cultivars commonly grown in western Canada over the past century (Table 2-1). The two sites were located within 500 m of one another with the same soil type (Orthic Black Chernozem). Plot dimensions were 4m by 1.38m, with 6 rows spaced 23cm apart, seeded with a no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada) in May. The organic site has been in a long term, three-year rotation of experimental spring-sown grain followed by a fall-sown rye taken for silage the following year, followed by a triticale-pea mixture again harvested for silage. The conventional site is in a long term four-year rotation in the following order: 1) experimental canola plots, 2) triticale-pea mixtures (or uniform pea) harvested as silage, 3) experimental spring wheat plots, and 4) barley silage.

Fertilizer application followed soil tests and local recommendations for the conventional site (Table 2-2). The conventional land had 112 kg ha^{-1} of N banded in the form of urea (46-0-0) in the fall. Thirty-six kg ha^{-1} of 11-52-0 was banded with the seed for 4 kg ha^{-1} of N and 19 kg ha^{-1} of P_2O_5 as urea and ammonium phosphate. The organic land had compost (comprised of non-organic dairy manure, sawdust, wood chips and straw) applied each year and incorporated with harrows for the 5 years prior to 2005 at a rate of 50-62 t ha^{-1} (fresh weight). No compost was added during the trial years of 2005 to 2007. Herbicide (Dyvel ®) was applied to the wheat at 1.2 L ha-1 at the recommended crop and weed stage in the conventional site only. Weeds were controlled in the fall and spring with tillage, with a final pass with a cultivator and harrows directly prior to seeding on the organic site.

Soil samples were taken in 2005 and 2006, approximately 60 days after seeding for phospholipid fatty acid analysis. Soil cores (0-15cm) were taken directly below five randomly chosen wheat plants from each plot (avoiding plot edges) and placed in plastic bags in storage at -20°C until subsampling. Two grams of rhizosphere soil was thawed and subsampled from each soil core and freeze-dried. Soil biological measures (described below) were determined using a phospholipid fatty acid analysis (PLFA) method described in Dalpé and Hamel (2007). Briefly, fatty acids were extracted using a dichloromethane : methanol : citrate buffer. Phospholipid fatty acids were separated from other lipids on solid phase extraction columns made from flamed glass pipettes and silica gel. Samples were methylated using a mild acid methanolysis and analyzed using a Hewlett Packard 5890 II Plus Gas Chromatograph with MIDI Inc. MIS (Microbial Identification System) Version 4 used for peak identification. Total biomass of PLFAs is expressed as micrograms PLFA per gram of dry soil. Weight of individual PLFAs in the sample are determined by comparing the area under a specific peak with the 19:0 peak value, which is determined using a standard curve of 19:0 FAME standard dissolved in hexane. Total PLFA was used to determine total viable biomass in the soil, and PLFA markers from DeGrood et al. (2005) were used to calculate the percent of total biomass as gram negative bacteria, gram positive bacteria, and actinomycetes. The PLFA marker 16:1w5 was used to indicate mycorrhizal fungi (Dalpé and Hamel 2007). Richness was determined by counting the number of unique PLFAs in a sample. Shannon's diversity index (Krebs 1989) was calculated for each soil sample using the formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Evenness was calculated using the formula:

$$E = H'/\ln S$$

Where H′ is Shannon's diversity index; S is the number of PLFAs in a sample; p_i is the proportion of the weight of individual PLFAs to the total weight of PLFAs in a sample. Total biomass was not significant for any effects (management regime and wheat cultivar) and will not be mentioned.

Grain was harvested using a Wintersteiger plot combine in late September or early October, depending on crop maturity and equipment availability. Harvested grain was dried at 40°C for approximately 48 hours. Yield was recorded over all three years. In 2006 and 2007 plant heights were recorded following stem elongation, from the ground surface to the top of the wheat spike (excluding awns). Most of the trash material collected with the harvested grain was weed seeds. Weed seeds were removed using sieves and a grain blower. The dry weight of the material removed from the grain was used as a measure of weed seed presence in the crop at harvest.

Breadmaking quality, including a number of processing measures which relate to final product quality was determined annually at the Cereal Research Centre, Agriculture and Agri-Food Canada, Winnipeg. Grain samples were ground using an UDY Cyclone Sample Mill (UDY Corporation, Fort Collins, CO, USA) using a 1.0 mm screen, and grain protein (PRO) and particle size index (PSI) were determined using a 3g flour sample in an Instalab 600 series Near-Infrared Reflectance Analyzer (DICKEY-john Corporation, Auburn, IL, USA) according to the AACC Approved Methods 39-10 and 39-70 (AACC, 2000). Flour yield (FLY) was determined with a Brabender Quadrumat Junior Mill (C.W. Brabender Instruments, South Hackensack, NJ, USA) according to the Approved Method 26-50 (AACC, 2000). Mixograph measures included mixing development time (MDT), peak height (PKH), total energy under the graph (TEG), energy to peak (ETP), and bandwidth energy (BWE). Mixograph parameters were obtained using a 10g fixed bowl mixograph (K&S Tool and Die Ltd, Winnipeg, MB, Canada) at 60% water absorption and were collected and analyzed as described by Pon et al. (1989).

Analyses of data were performed using the PROC MIXED procedure of SAS. The experiment was analysed as a split plot with management system as the main plot and cultivar as the sub plot. Using such an analysis implies that one complete block was grown per year. Thus, years were treated as blocks and were considered as a random effect in both combined analysis and analysis by management system. Cultivar and management system (where applicable) were considered as fixed effects. We also analyzed data by management system, combined over years. For both analyses, years and blocks were considered random and management system and cultivar were considered fixed effects. Pearson correlations were conducted on plot means for the organic and conventional sites. The split-plot design has a decreased precision for main plot (management) comparisons (Steel et al. 1997), which was of interest to us. Preliminary analysis revealed no significant differences in microbial community among the wheat cultivars in the organic system. To test for differences between the management main effects (excluding cultivar effects) for the soil PLFA profiles a Student's t-test was conducted using Proc TTEST. We discuss and report differences between treatments only when $P \leq 0.05$, except for the mixed model analysis of the experiment, where $P \leq 0.10$ was used as a significance level appropriate for the small experimental size (Steel et al. 1997).

2.3 Results and Discussion

Agronomic Properties and Yield

There were differences between the organic and conventional systems for crop productivity, agronomic measures, breadmaking quality and the soil microbial community. The organic and conventional systems examined in this study shared identical soil types, similar soil properties and climatic conditions (Table 2-3). Differences between the two management systems were thus the result of different production practices; including fertility and tillage regime, crop rotation and weed control. Differences in the soil properties due to management regimes are still slight, most likely due to the close proximity of the sites, and that the organic site has been managed differently for just six field seasons at the start of this study. Management altered weed seed mass and grain yield. Weed pressure was extremely high in the organic system, with the weight of weed seeds at harvest nearly seven times greater than the conventional system (P=0.07, Table 2-3). Organic grain yields (2.74 t ha^{-1}) were roughly one-half of conventional yields (5.02 t ha^{-1}) (P=0.06), which is indicative of the trend to lower yields in organic systems (Entz et al. 2001). The yield loss in the organic system is partly attributable to crop competition with weeds, which has been reported to reduce wheat yields under organic systems by up to 34% (Mason et al. 2007a). The organic system had later seeding dates than the conventional system in all three trial years (to allow some weeds to emerge and be controlled prior to seeding) (Table 2-2); delayed seeding has been reported to lower grain yields (Hunt et al. 1996). This is a confounding factor of the present experimental design, reflecting the agronomic reality that organic farmers tend to wait for the first flush of weeds to work the soil and plant.

Cultivars varied for all agronomic traits when combined over management systems. Within management systems, cultivars varied for all traits except weed biomass in the conventional system (where weeds were generally eliminated with herbicides). Management × cultivar interaction was significant for height, weed seed mass and yield (Table 2-4). The oldest and tallest cultivar, Marquis, had the lowest yield in both the organic (2.4 t ha^{-1}) and conventional (4.0 t ha^{-1}) sites. Lodging did not occur in any of the cultivars in this study. AC Superb, the most recently developed and shortest cultivar, had the highest yields in both systems (3.1 t ha^{-1} in organic and 5.7 t ha^{-1} in conventional). Plots with Glenlea had significantly lower weed seed pressure at harvest than AC Elsa and AC Superb in the organic system. AC Superb and Glenlea had higher yields than the other three cultivars in the conventional system, but in the organic system only AC Superb yielded higher than Marquis (the lowest yielding cultivar).

2.3.1 Breadmaking Quality

Management system altered grain protein ($P<0.05$), flour yield ($P=0.10$), particle size index ($P=0.10$), peak height ($P=0.09$) and total energy under the graph ($P=0.06$, Table 2-4). The inclusion of delayed seeding in the organic system may be an important contributor to these observed differences. Although most of the quality traits varied between the organic and conventional grain, both systems had acceptable quality levels. Grain protein levels were higher in the organic system (16.6%) than in the conventional system (15.3%); however, protein levels were high for all cultivars at both the organic and conventional sites, with values above the minimum standard for CWRS wheat of 13.5%. Flour yield and particle size index were lower in the organic system, while peak height and total energy under the graph were higher in the organic system. Organic grain quality equal to or better than conventional systems is possible to achieve.

The management × cultivar interaction effect was significant for protein, mixing development time and peak height (Table 2-4). Glenlea and Marquis exhibited rank reversals within the two management systems for protein content. Glenlea had the lowest protein content in the conventional system, and the highest in the organic system. Marquis had similar protein levels in both management systems (15.6% in conventional and 16.0% in organic), but its ranking changed from the second highest protein content in the conventional system, to the lowest protein content in the organic system.

Cultivars varied for all breadmaking traits except protein in the combined analysis, and varied for all traits when analyzed separately by management system (Table 2-4). For most traits, the cultivars had acceptable breadmaking quality levels for CWRS wheat (Mason et al. 2007b). Glenlea had a long mixing development time under conventional management. The longer mixing development time, higher energy to peak and bandwidth energy of Glenlea indicate higher gluten strength, which is a major trait of this cultivar. Glenlea is in the Canada Western Extra Strong class, with strong gluten and high kernel hardness, and can be blended with other wheats to raise flour gluten strength (McCallum and DePauw 2008). Long mixing development times are undesirable in the CWRS wheat class as it affects the processing schedules of commercial bakers.

2.3.2 Soil Microbial Diversity

We employed a Student's t-test to compare the soil PLFA profiles of the organic and conventional sites without including the effect of cultivar. This provided a greater sampling size which allowed a more precise comparison of the two systems. The organic system had higher % gram negative and gram positive bacteria and % mycorrhizal fungi than the conventional system (Figure 2-1). Richness and diversity were also greater in the organic system than the conventional system. Measured soil microbial profiles differed between the two management systems. Weeds were more prevalent in the organic system, and we believe their presence contributed to the microbial differences present between the two management systems. Increases in above-ground diversity have been reported to increase soil microbial diversity (Garbeva et al. 2006). The organic system, with a greater diversity of plants (including weeds) had higher levels of bacteria and fungi, as well as higher PLFA richness and diversity. Differential effects of plant species, including weeds, on soil microbial communities may be caused by differences in plant material composition and plant root exudates.

The use of composted manure in the organic system may have also led to differences in the soil microbial community. The addition of manure to a soil increases microbial biomass, and may alter the community structure of soil microbes by increasing soil organic carbon (Frostegård et al. 1997; Fauci and Dick 1994). The type of substrate added (e.g. compost versus fresh plant material) may or may not affect community structure including indirectly through effects on soil water content (Drenovsky et al. 2004; Fauci and Dick 1994). The handling of manure prior to application also appears to have an effect. Fließbach and Mäder (2000) reported that microbial communities supplied greater stabilized organic matter in biodynamically composted manure with a lower metabolic quotient than those supplied uncomposted manure.

The management × cultivar interaction effect was significant for % Gram negative bacteria, % Gram positive bacteria, evenness and diversity (Table 2-5). There was greater % Gram negative bacteria in the organic system. In the organic system, the soil under the five cultivars did not differ for any of the soil microbial measures recorded. In the conventional system, the cultivar AC Superb had greater levels of % mycorrhizal fungi, evenness and diversity in the root rhizosphere soil than other cultivars.

The weeds present in the organic system may have masked the influence of cultivar on the soil microbial community structure, which was only detected in the relatively weed-free conventional system. The cultivars in the conventional system differed for the proportion of fungi present, as well as the PLFA evenness and diversity. The most recent (and highest yielding) cultivar, AC Superb, exhibited the highest levels of all traits; most notably % fungi. This indicates that AC Superb had the highest level of mycorrhizal presence of the studied cultivars in the conventional system. Some studies suggest that mycorrhizal dependency is being bred out of modern wheat cultivars (Hetrick et al. 1993; Zhu et al. 2001). Our results suggest that breeding efforts in conventionally managed environments may have resulted in cultivating mycorrhizal dependence in that environment.

Productivity and quality traits were significantly correlated with a number of the soil PLFA measures. In the organic system, gram negative bacteria, actinomycetes and measures of diversity were all positively correlated with weed seed yield (Table 2-6). This supports our earlier hypothesis that increased plant diversity in the organic system (due to weeds) led to higher diversity of soil microbes. In the conventional system, weed seed yield was negligible, with no significant correlations between it and soil microbial measures. Weed biomass may have been a better measure of weed pressure in a conventional environment where weeds were controlled through pesticides.

In both the organic and conventional systems, the measures of diversity were all negatively correlated with crop yield, and had mainly negative correlations with breadmaking quality parameters (Tables 2-6 and 2-7). This indicates that the presence of weeds, while increasing soil microbial diversity, had a detrimental effect on productivity, and possibly quality as well. It appears that soil microbial diversity increased through the presence of weeds had no discernable positive effect of crop productivity or quality. There were some moderate positive correlations between microbial diversity and breadmaking quality parameters in the conventional system (Table 2-7).

In the organic system, the proportion of mycorrhiza fungi in the soil had a strong positive correlation with yield (Table 2-5). Arbuscular mycorrhizal fungi were positively correlated with measures of productivity and breadmaking quality traits in the organic system only. Arbuscular mycorrhizal fungi form (generally) mutualistic associations with the roots of the majority of known plant species, including wheat. Arbuscular mycorrhizal fungi are beneficial to plants in the uptake of relatively immobile nutrients such as phosphorus, copper and zinc by increasing the soil surface area accessed for absorption of plant essential nutrients. The presence of a relationship between fungi and yield in the organic system only indicates that mycorrhizal fungi had a positive role in productivity of wheat plants in the organic system but no effect in the conventional system. Greater mycorrhizal potential and actual colonization has been repeatedly reported to be greater in organic and low-input systems versus conventional systems, in large part due to lowered application of phosphorus fertilizers in organic systems (Ryan and Graham 2002). Applications of phosphorus fertilizers has been reported to lower mycorrhizal colonization and decrease the relative benefits of mycorrhiza to crop productivity (Hamel and Strullu 2006). In this study, soil phosphorus levels were similar between the two systems in two of three study years (Table 2-3).

Fungi were negatively correlated with weeds in the organic system suggesting that the weeds in the organic system discouraged the presence of mycorrhizal fungi. Most of the weeds present in the organic system were non-mycorrhizal plants, including: redroot pigweed (*Amaranthus retroflexus* L.), lamb's quarters (*Chenopodium album* L.), and smartweed (*Polygonum lapathifolium* L.) (Vatovec et al., 2005). Non-mycorrhizal weeds present with wheat have been found to lower mycorrhizal colonization of the crop (Stejskalova 1990). Considering the strong positive relationship between fungi and crop yield, the presence of weeds, especially non-mycorrhizal weeds, should be discouraged. However, crop polycultures that include mycorrhizal crops may improve colonization of wheat plants.

Protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems. Increased microbial diversity may be possible to achieve through the use of crop polycultures that include plants that benefit the soil microbial community and crop quality, such as legumes and mycorrhizal plants. The most recently released cultivar had the highest levels of mycorrhizal fungi present in the rhizosphere of the conventional system. This study does not support the conclusion that wheat breeding efforts undertaken in conventional environments selects for cultivars with lower mycorrhizal dependence.

2.4 Summary

Wheat (*Triticum aestivum* L.) cultivars may have differential effects on soil microbial communities and the breadmaking quality of harvested grain. We conducted a field study comparing five Canadian spring wheat cultivars grown under organic and conventional management systems for yield, breadmaking quality and soil phospholipid fatty acid (PLFA) profile. Organic yields (2.74 t ha-1) were roughly one-half of conventional yields (5.02 t ha-1), but protein levels were higher in the organic system than the conventional system (16.6% vs. 15.3%, respectively). Soil microbial diversity measures were significantly higher in the organic system compared to the conventional system, including PLFA richness (31 vs. 27 unique PLFAs per sample, respectively) and PLFA diversity (Shannon diversity indexes of 2.90 and 2.73, respectively). Diversity measures were positively correlated with weed seed yield in the organic system ($0.44 < r < 0.55$), indicating that the presence of weeds played some role in increased microbial diversity. The use of composted dairy manure in the organic system may have also contributed to differences between the microbial communities in the organic and conventional systems. In the conventional system, the most recent wheat cultivar, AC Superb had higher levels of mycorrhizal fungi in the soil (1.97%) than the other cultivars (1.32-1.43). Our results suggest that breeding efforts in conventionally managed environments may have resulted in cultivating mycorrhizal dependence in that environment. Cropping systems that include a diversity of plants, such as polycultures, may increase soil microbial diversity.

2.5 Tables and Figures

Table 2-1: Summary of some characteristics of five wheat cultivars grown in experiment.

	Year of registration	Wheat class[z]	Maturity[y]	Height (cm)[x]	Parentage
Marquis	1910	CWRS	2	113	Red Fife x Hard Red Calcutta
Park	1963	CWRS	-2	91	(Mida x Cadet) x Thatcher
Glenlea	1972	CWES	0	-	(Pembina x Bage) x CB100
AC Elsa	1996	CWRS	0	89	BW90 x Laura
AC Superb	2000	CWRS	1	85	Grandin*2 x AC Domain

[z] CWRS: Canadian Western Hard Red Spring Wheat, CWES: Canadian Western Extra Strong Wheat

[y] Compared to AC Barrie: 106 days to maturity. Source: (Mason et al. 2007; Anderson 2009)

[x] Height information taken from Anderson (2009) and cultivar release information

Table 2-2: Seeding dates and other agronomic practice differences between organic and conventional wheat crops.

	Seeding date	Fertility amendments	Weed control
Organic 2005	May 19	No synthetic fertilizer, compost applied prior to 2005[z]	Fall and spring tillage, prior to seeding
Conventional 2005	May 10	Urea banded in fall, ammonium phosphate put down with seed[z]	Herbicide (Dyvel®) applied in-crop[z]
Organic 2006	May 31	No synthetic fertilizer, compost applied prior to 2005	Fall and spring tillage, prior to seeding
Conventional 2006	May 11	Urea banded in fall, ammonium phosphate put down with seed	Herbicide (Dyvel®) applied in-crop
Organic 2007	May 24	No synthetic fertilizer, compost applied prior to 2005	Fall and spring tillage, prior to seeding
Conventional 2007	May 14	Urea banded in fall, ammonium phosphate put down with seed	Herbicide (Dyvel®) applied in-crop

[z] Application rates found in Materials and Methods

Table 2-3: Soil properties for 0-15cm depth soil samples at the organic and conventional sites in the 2005-2007 growing seasons, prior to seeding in Edmonton, AB, Canada.[z]

Year	NO_3 *(kg ha^{-1})*	P *(kg ha^{-1})*	K *(kg ha^{-1})*	SO_4 *(kg ha^{-1})*	Organic matter *(%)*	pH
			Organic			
2005	199	260	1582	>90	10.3	6.1
2006	227	262	1581	>85	12.9	6.3
2007	56	83	533	16	14.6	6.4
			Conventional			
2005	272	192	1462	>90	7.2	7.3
2006	252	213	1352	60	12.8	5.9
2007	41	>134	965	21	12.5	6.6

[z] Available N and SO_4 determined using $CaCl_2$ extraction; available P and K determined using modified Kelowna extract (Norwest Labs)

Table 2-4: LSmeans and results of statistical analysis for selected agronomic and breadmaking quality traits for five spring wheat cultivars grown organically and conventionally in Edmonton, AB in 2005, 2006 and 2007.[z]

Cultivar	Height (cm)	Weed seed mass (kg ha^{-1})	Yield (t ha^{-1})	Grain protein (%)	Flour yield (%)	Particle size index (%)	Mixing development time (min.)	Peak height	Energy to peak	Bandwidth energy	Total energy under graph
Organic											
AC Elsa	84	380	2.80	16.8	72	51	2.2	61.3	92	90	274
Glenlea	85	230	2.78	17.2	69	49	3.1	62.4	139	114	298
Marquis	96	346	2.38	16.0	69	52	3.0	53.1	110	104	268
Park	85	294	2.65	16.7	71	51	2.3	53.0	87	87	244
AC Superb	76	355	3.11	16.3	70	50	1.9	59.3	79	86	261
F $test_{cultivar}$	***	***	***	***	***	***	***	***	***	***	***
$SE_{cultivar}$	12.5	112.9	0.796	0.350	1.0	1.4	0.26	3.00	9.8	14.4	13.5
Conventional											
AC Elsa	91	46	5.09	16.0	74	53	2.0	59.7	82	85	263
Glenlea	102	41	5.57	14.5	73	50	4.9	48.0	166	107	245
Marquis	103	47	4.04	15.6	71	54	1.7	47.8	57	70	211
Park	97	46	4.66	15.3	72	54	2.1	48.5	69	75	220
AC Superb	83	50	5.73	15.0	74	52	2.1	52.0	71	79	230
F $test_{cultivar}$	***	ns	***	***	***	***	***	***	***	***	***
$SE_{cultivar}$	1.2	22.7	0.421	0.17	0.6	0.7	0.15	1.07	6.4	8.6	11.3
$Mean_{organic}$	85	320	2.74	16.6	70	51	2.5	57.8	101	96	269
$Mean_{conventional}$	95	46	5.02	15.3	73	53	2.6	51.2	89	84	234
F $test_{management}$	ns	*	*	**	*	*	ns	*	ns	ns	*
$SE_{management}$	8.9	80.1	0.631	0.24	0.7	1.1	0.15	1.98	5.7	11.2	10.6
F $test_{cultivar}$	***	***	***	ns	*	***	***	***	***	**	***
$SE_{cultivar}$	6.3	57.6	0.467	0.27	0.8	1.1	0.24	2.05	9.0	11.8	11.9
F $test_{m*c}$	*	***	**	**	ns	ns	***	**	ns	ns	ns

[Z] ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01, SE=standard error

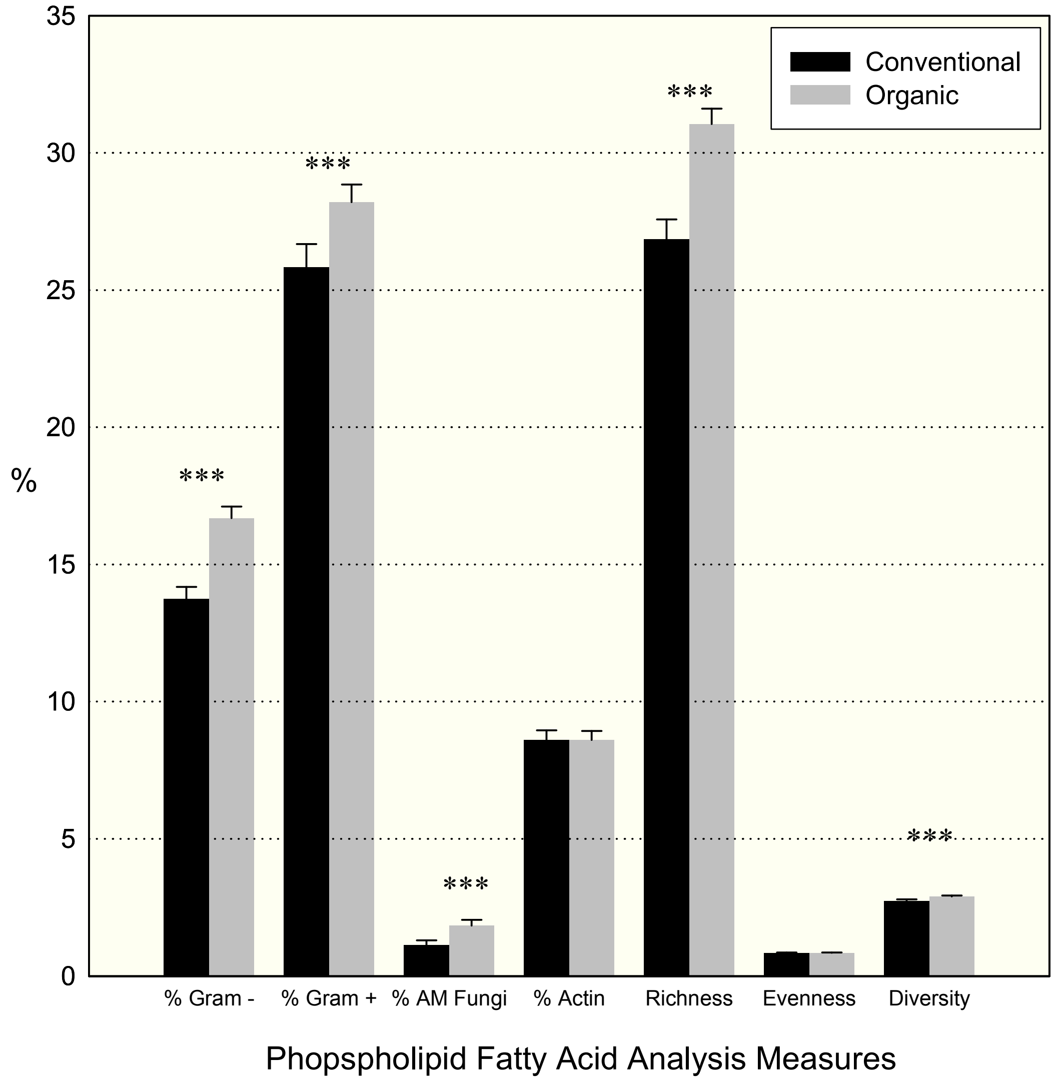

Figure 2-1: Means and confidence limits of phospholipid fatty acid analysis measures for wheat grown on organic and conventional sites in Edmonton in 2005 and 2006. The *** above the bars indicate that the means are significantly different at <0.01 as determined by Student's t-test.

Table 2-5: LSmeans and results of statistical analysis on selected PLFA measurements for five wheat cultivars grown organically and conventionally in Edmonton, AB.[z]

Cultivar	% Gram negative	% Gram positive	% AM Fungi	% Actin.	Richness	Evenness	Diversity
				Organic			
AC Elsa	17.0	28.7	2.33	5.6	32	0.86	2.95
Glenlea	17.0	30.0	2.45	5.7	31	0.86	2.93
Marquis	16.7	28.1	2.32	5.8	32	0.84	2.91
Park	17.2	27.9	2.37	5.6	30	0.85	2.89
AC Superb	16.1	27.2	2.18	5.7	31	0.82	2.83
F $test_{cultivar}$	ns	ns	ns	ns	ns	ns	ns
$SE_{cultivar}$	1.00	1.24	0.445	0.98	1.5	0.029	0.140
				Conventional			
AC Elsa	13.6	26.1	1.32	5.7	26	0.84	2.70
Glenlea	13.3	25.0	1.41	5.9	27	0.81	2.67
Marquis	13.9	25.9	1.34	5.9	27	0.84	2.75
Park	12.7	24.5	1.43	5.6	26	0.80	2.61
AC Superb	14.8	26.9	1.97	6.2	28	0.87	2.87
F $test_{cultivar}$	ns	ns	**	ns	ns	*	*
$SE_{cultivar}$	1.14	3.55	0.170	1.11	3.1	0.058	0.284
$Mean_{organic}$	16.8	28.3	2.33	5.7	31	0.85	2.90
$Mean_{conventional}$	13.7	25.7	1.49	5.9	27	0.83	2.73
F $test_{management}$	***	ns	ns	ns	ns	ns	ns
$SE_{management}$	0.95	2.52	0.317	1.03	2.3	0.044	0.215
F $test_{cultivar}$	ns	ns	ns	ns	ns	ns	ns
$SE_{cultivar}$	0.99	2.23	0.247	1.03	2.2	0.042	0.205
F $test_{m*c}$	*	**	ns	ns	ns	***	**

[z] ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01, SE=standard error

Table 2-6: Pearson correlation coefficients between means of crop productivity, quality and PLFA traits for five wheat cultivars grown organically in Edmonton in 2005 and 2006.[z]

	Gram -	Gram +	AM Fungi	Actin	Richness	Evenness	Diversity
Yield	-0.35	-	0.63	-0.76	-0.59	-0.47	-0.62
Weed	0.35	-	-0.50	0.68	0.44	0.46	0.55
Particle size index	-	-	0.57	-0.60	-	-0.35	-0.41
Falling number	-	-	0.37	-0.54	-	-0.40	-0.44
Flour yield	-	-	0.38	-0.43	-0.47	-	-0.45
Mixing development time	-	0.34	-	-	-	-	-
Peak height	-	-	-0.45	-	-	-	-
Bandwidth energy	-	0.36	-	-	-	0.37	-
Total energy under graph	-	-	-0.46	0.43	-	-	-

[z] Parameters with no significant correlations at $P<0.05$ are not shown; - indicates correlation not significant ($P>0.05$).

Table 2-7: Pearson correlation coefficients between means of crop productivity, breadmaking quality and PLFA measurements for five wheat cultivars grown conventionally in Edmonton in 2005 and 2006.[z]

	Gram -	Gram +	AM Fungi	Actin	Richness	Evenness	Diversity
Yield	-	-0.39	-	-0.45	-0.42	-0.34	-0.40
Protein	-	-	-0.46	-	-	-	-
Flour yield	-0.41	-0.59	-	-0.56	-0.58	-0.48	-0.56
Peak bandwidth	-	0.34	-	-	-	-	-
Bandwidth energy	-	0.40	-	0.42	0.41	-	0.34
Total energy under graph	-	0.40	-	0.36	-	0.35	0.35

[z] Parameters with no significant correlations at P<0.05 are not shown; - indicates correlation not significant (P>0.05).

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3.0 The soil microbial community and grain micronutrient concentration of historical and modern hard red spring wheat cultivars grown organically and conventionally in the black soil zone of the Canadian Prairies[3]

3.1 Introduction

Consumers purchase organic food products because they perceive these foods to have unique attributes and/or superior quality attributes relative to conventional foods (Yiridoe et al. 2005). Organic food products are viewed as more healthy, safe and/or environmentally friendly than conventional food products (Yiridoe et al. 2005). Consumers list a number of benefits of organic products as important in their choice to buy organic from most important to least important: health, environment, taste, animal welfare, minimal processing, novelty and fashion (Lockie et al. 2006). Despite the perceived benefits of consuming organic foods, organic certification is based on the process used to produce the good, not on the product itself, meaning that organic certification is not a guarantee of a superior product (Brandt and Mølgaard 2007). Many of the perceived attributes of organic products cannot be measured, and necessitate faith on the part of the consumer that the desired attributes are present (Ritson and Oughton 2007).

Micronutrients play important roles in human body functioning and health. Deficiencies are most generally present in developing countries, often affecting women and children (WHO/FAO 1998). However, at least one-half the US population fails to meet the recommended dietary allowance for the micronutrients magnesium (Mg), calcium (Ca), and zinc (Zn) (Cordain et al. 2005). Essential trace elements Zn, copper (Cu) and Se are antioxidant micronutrients. They play a key role in the body's defenses against free radicals and reactive oxygen molecules as constituents of antioxidant enzymes. Increasing mineral nutrient content of crops, or biofortification, can help prevent nutrient deficiencies. Biofortification may be achieved through agronomic measures to increase the availability of mineral elements in the soil, as well as the

[3] *A version of this chapter has been published. Nelson, A.G., Quideau, S.A., Frick, B., Hucl, P.J., Thavarajah, D., Clapperton, M.J. and Spaner, D.M. 2011. Sustainability 3(3): 500-517.*

development and use of crops with increased ability to absorb nutrients (White and Broadley 2009). Globally, wheat is a major source of nourishment and the main source of carbohydrates in temperate areas (Leonard and Martin 1963). There has been speculation that the development of high yielding cultivars in association with input intensification has resulted in lower levels of micronutrients in grains produced in conventional environments. In a meta-analysis study, Worthington (2001) reported that organic crops contained significantly more Fe and Mg than conventional crops. There were nonsignificant trends showing a higher content (e.g. mg of mineral) of nutritionally significant minerals in organic crops. Murphy et al. (2008) reported, in a Pacific Northwest USA study of 63 historical and modern wheat cultivars that, while grain yield has increased over time, the concentrations of all minerals except Ca have decreased. They further reported that the decrease in mineral concentration over the past 120 years occurred mainly in the soft white wheat and not the hard red market class.

Soils, climate, crop type and cultivar, management practices and post-harvest factors can all affect the nutritional quality of crops (Hornick 1992). Research into nutritional differences between organic and conventional crops has yielded conflicting results or small differences (Bourn and Prescott 2002). Mäder et al. (2007) reported few differences in nutrient content of organic and conventional wheat grain in a long-term field study. Ryan et al. (2004) found that the nutritional value of organic grain was slightly better than conventional grain, with higher Zn and Cu concentrations in organic wheat. However, the authors concluded that universal statements about differences between organic and conventional management were not useful, but that knowing the underlying mechanisms leading to nutritional quality differences could lead to improved nutritional quality. In another long-term field study, Turmel et al. (2009) reported that differences in grain mineral content of organic and conventional wheat are dependent on the system's crop rotation (annual grain vs. perennial forage-grain rotation). Compost has also been reported to influence soil micronutrient content and crop uptake in organic and conventional systems (Warman and Havard 1998).

Soil microbes affect soil fertility in many ways, for instance through their influence on organic matter turnover, mineral immobilization and dissolution, and soil aggregation (Davis and Abbott 2006). As well, soil microbes such as *Rhizobia* bacteria and arbuscular mycorrhizal fungi form plant symbioses, improving plant nutrient supply or uptake. While management practices can alter microbial communities directly, for the most part, management practices change microbial communities indirectly by altering soil properties affecting microbial diversity. Because most microbes are heterotrophic, soil organic matter content and the type and amount of organic materials added to the soil are two critical soil factors affecting microbial diversity (Shannon et al. 2002). Genetic differences within a crop species (i.e. cultivar differences) may play a role in the structure of the microbial community. Differences have been found in microbial communities associated with different wheat and canola (*Brassica napus* L.) cultivars (Siciliano et al. 1998).

Both organic and conventional cropping systems consist of a number of different management practices (chemical use, tillage, crop rotation and crop choice) used in combination. Despite the ranges of management practices used on organic and conventional cropping systems, there are a number of factors which commonly differ between the two systems. On the western Canadian prairies, according to research conducted over the last 10 years, organic systems tend to have higher organic matter, more weeds, lower yields and lower phosphorus (P) levels than conventional systems (Entz et al. 2001; Snyder and Spaner 2010). The absence of inorganic fertilizers and pesticides in organic systems generally leads to greater weed populations, higher tillage intensities, and lower soil nutrient levels. Thus, at least in extensive grain producing systems of the northern Great Plains, organic systems generally tend to present greater biotic and abotic stresses to production systems than their conventional counterparts (Snyder and Spaner 2010).

Organic systems often have more diverse crop rotations and higher plant diversity within fields than conventional systems. Organic systems employ a number of practices that serve to increase organic matter content, generally resulting in slightly higher levels of organic matter in organic systems versus conventional systems (Bossio et al. 1998; Shepherd et al. 2002). Some studies have reported shifts in microbial communities with organic versus conventional management (Bossio et al. 1998; Lundquist et al. 1999), while others have reported no differences between microbial communities under the two management systems (Wander et al. 1995; Girvan et al. 2003).

We hypothesized that the stress levels associated with organic management systems would result in higher levels of micronutrients in the grain, and specifically those with antioxidant properties. We further hypothesized that western Canadian historic hard red spring cultivars would have higher mineral content than modern cultivars, especially in organic systems; and that those organic systems would have a more diverse microbial community structure. Thus, the objectives of this study were to compare the concentrations of seven minerals, including Se, Cu, Mn, Zn, Fe, Mg and K in a subset of hard spring wheat cultivars grown over the last 100 years in western Canada in both conventional and organic environments. We were also interested in exploring the relationship between the microbial community structure in the two management systems and grain micronutrient content.

3.2 Materials and Methods

We reported the effect of cultivar and management system (organic vs. conventional) on agronomic traits, soil biotic data and breadmaking quality traits using the present experimental design (Nelson et al. in press). The present study is thus a continuation of a reported study where the experimental design is similar in many respects. To summarize, we grew five western Canadian spring wheat cultivars (AC Elsa, Glenlea, Marquis, Park and AC Superb) in four-replicate, randomized complete block experiments: one organically managed site and one conventionally managed site in 2005, 2006 and 2007 in Edmonton, AB (55°34´N, 113°31´W). The cultivars were chosen to represent spring wheat cultivars commonly grown in western Canada over the past century (Table 3-1). The two sites were located within 500 m of one another with the same soil type (Orthic Black Chernozem). Plot dimensions were 4m by 1.38m, with 6 rows spaced 23cm apart, seeded with a no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada) in May. The organic site has been in a long term, three-year rotation of experimental spring sown grain followed by a fall-sown rye taken for silage the following year, followed by a triticale-pea mixture again harvested for silage. The conventional site is in a long term four-year rotation in the following order: 1) experimental canola plots, 2) triticale-pea mixtures (or uniform pea) harvested as silage, 3) experimental spring wheat plots, and 4) barley silage.

Fertilizer application followed soil tests and local recommendations for the conventional site (Table 3-2). The conventional land had 112 kg ha^{-1} of N banded in the form of urea (46-0-0) in the fall. Thirty-six kg ha^{-1} of 11-52-0 was banded with the seed for 4 kg ha^{-1} of N and 19 kg ha^{-1} of P_2O_5 as urea and ammonium phosphate. The organic land had compost (comprised of dairy manure, sawdust, wood chips and straw) applied each year for the 5 years prior to 2005 at a rate of 50-62 t ha^{-1} (fresh weight). No compost was added during the trial years of 2005 to 2007. Herbicide (Dyvel ®) was applied at 1.2

L ha-1 at the recommended crop and weed stage in the conventional site only. Weeds were controlled in the fall and spring with tillage, with a final pass with a cultivator and harrows directly prior to seeding on the organic site.

Soil samples for nutrient determination were taken prior to seeding in the spring over entire trial site, bulked and subsampled. Soil samples for phospholipid fatty acid analysis were taken approximately 60 days after seeding. Soil cores (0-15cm) were taken directly below five randomly chosen wheat plants from each plot and placed in plastic bags in storage at -20°C until subsampling. The soil cores were placed in plastic bags in storage at -20°C until subsampling. Two grams of soil was subsampled from each soil core at the origin of root growth where roots were most dense (to collect rhizosphere soil) and freeze-dried.

We harvested the wheat plots using a Wintersteiger plot combine in late September and early October, depending on crop maturity. Harvested grain was dried at 40°C for approximately 48 hours. Weed seeds were removed using sieves and a grain blower. Most of the trash material collected with the harvested grain was weed seeds. The weight of the material removed from the grain was used as a measure of weed seed presence in the crop at harvest. Yields were recorded over all three years.

Composition of the soil microbial community was determined using the phospholipid fatty acid analysis (PLFA) method as described by Dalpé and Hamel (2007). In brief, fatty acids were extracted using a dichloromethane : methanol : citrate buffer. Phospholipid fatty acids were separated from other lipids on solid phase extraction columns made from flamed glass pipettes and silica gel. Samples were methylated using a mild acid methanolysis. Samples were analyzed using a Hewlett Packard 5890 II Plus Gas Chromatograph with MIDI Inc. MIS (Microbial Identification System) Version 4 used for peak identification. Weight of individual PLFAs in the sample are determined by comparing the area under a specific peak with the 19:0 peak value, which was determined using a standard curve of 19:0 Fatty acid methyl ester (FAME) standard dissolved in hexane. PLFA markers from DeGrood et al. (2005) were used to calculate the percent of total biomass as gram negative bacteria, gram positive bacteria, and actinomycetes. The PLFA marker 16:1w5 was used to indicate mycorrhizal fungi (Dalpé and Hamel 2007). Richness was determined by counting the number of unique PLFAs in a sample. Shannon's diversity index was calculated for each soil sample using the formula:

$$H' = -\sum_{i=1}^{s} p_i \ln p_i$$

Evenness was calculated using the formula:

$$E = H'/\ln S$$

Where H´ is Shannon's diversity index; S is the number of unique PLFAs in a sample; p_i is the proportion of the weight of individual PLFAs to the total weight of PLFAs in a sample.

Micronutrient traits were determined on the whole grain at the Crop Development Centre (CDC), Saskatoon, SK. A subsample of 100g of dry seed was taken from each plot, ground and prepared following a standard HNO_3 H_2O_2 digestion method for Se (Thavarajah et al. 2007) and for the other elements (Thavarajah et al. 2009). CDC Redberry lentil seeds and organic wheat were used as laboratory reference materials and measured periodically to ensure consistency in the method. Total micronutrient (Mg, K, Mn and Cu) concentrations were measured using flame- AAS (AJ ANOVA 300, Lab Synergy, Goshen, NY, USA). Total Se concentrations before and after cooking were measured using hydride generation (HG)-AAS (AJ ANOVA 300, Lab Synergy, Goshen, NY, USA).

The organic and conventional sites were less than 500 m apart, with similar growing temperatures and precipitation levels within years (data not presented); thus differences between the two systems are likely due to the different management strategies and the resulting differences in nutrient levels (Table 3-2) and weed pressure. Analyses of data were performed using the PROC MIXED procedure of SAS. The experiment was analysed as a split plot with management system as the main plot and cultivar as the sub plot. Using such an analysis implies that one complete block was grown per year. Thus, years were treated as blocks and were considered as a random effect in both combined analysis and analysis by management system. Cultivar and management system (where applicable) were considered as fixed effects. We also analyzed data by management system, combined over years. For both analyses, years and blocks were considered random and management system and cultivar were considered fixed effects. Pearson correlations were conducted on plot means for the organic and conventional sites. The split-plot design has a decreased precision for main plot (management) comparisons (Steel et al. 1997), which was of interest to us. Preliminary analysis revealed no significant differences in microbial community among the wheat cultivars in the organic system. We discuss and report differences between treatments only when $P \leq 0.05$, except for the mixed model analysis of the experiment, where $P \leq 0.10$ was used as a significance level appropriate for the small experimental size (Steel et al. 1997).

The structure of the microbial community (PLFA) for the entire experiment, and for the two management systems separately was characterized with non-metric multidimensional scaling (NMS) ordination using PC-ORD (version 5, MjM Software Design). Statistical analyses were conducted on the mean laboratory results of the five sub-samples per plot. Fatty acids present in less than 10% of the samples were omitted from the analysis. A total of 43, 47 and 40 unique PLFAs were used in the combined management system, organic and conventional ordinations, respectively. The PLFA data were arcsine square-root transformed prior to ordination. A Sorensen (Bray-Curtis) distance measurement was used in all ordinations. Biplots were used to show the relationship between grain micronutrient concentration, yield and PLFA ordination scores.

Significant differences between management system, year and wheat cultivars were evaluated on the NMS analyses using a multi-response permutation procedure (MRPP). Indicator species analyses were used to evaluate the relationship between individual PLFAs and the two management systems.

The experiments were conducted on a single organic/conventional site comparison and differences between the management systems are therefore specific to the site soil and growing conditions. These results should be interpreted in conjunction with further data compiled in this region (eg. Synder and Spaner 2010).

3.3 Results

Yields were significantly lower in the organic system than the conventional system (2.74 vs. 5.02 t ha^{-1}, respectively) (Table 3-3). AC Superb (the most modern and semi-dwarf cultivar) yielded the most grain, and Marquis (the oldest cultivar) the least in both systems. Flour yield was significantly higher in the conventional system than the organic system. AC Elsa (a modern tall cultivar) had the highest flour yields in both the organic and conventional systems. Weed biomass was over six times greater in the organic system than the conventional system. Most of the weeds present in the organic system were redroot pigweed (*Amaranthus retroflexus* L.), lamb's quarters (*Chenopodium album* L.), and smartweed (*Polygonum lapathifolium* L.). Full agronomic and baking quality data and analyses for this study have been reported elsewhere (Nelson et al. 2011).

3.3.1 Grain micronutrient concentration

In the organic system, Glenlea had the highest levels of Zn, Mn, Mg, K and Fe, followed by the most recent cultivars AC Elsa or AC Superb (Figure 3-1). In the conventional system, the historical cultivar Marquis had the highest levels of Zn, and Park (1963 release) had the highest Mg levels; the modern cultivars had the highest K (AC Superb and Fe (AC Elsa) grain concentrations. Under conventional management, Glenlea had intermediate to low levels of grain micronutrients (Figure 3-1).

There were significant management × cultivar interactions for Cu, Mn, Zn, Fe, Mg and K (Table 3-3). AC Elsa grown conventionally had higher levels of grain Cu than AC Elsa, Marquis and Park grown organically. Organically grown Glenlea had higher grain Mn, Zn, Fe, Mg and K concentrations than other organically and conventionally grown cultivars. In the organic system, Glenlea grain had higher Mn, Fe and K levels than Park, higher Mn and Mg levels than AC Elsa and higher Zn concentration than AC Superb. Organically grown Glenlea grain also had higher Fe than conventional Park and AC Superb, and higher K concentration than conventional Park and Marquis grain.

On average, the conventional system had higher ($P<0.05$) grain Se and Cu concentration, while the organic system had higher grain Zn, Fe, Mg and K levels. In the organic system, grain yield and flour yield were negatively correlated with grain Zn, Fe and Mg concentrations (Table 3-4). In the conventional system, only grain Mg concentration was negatively correlated with both grain and flour yield. Grain protein content was positively correlated with Zn in both systems, and Fe in the organic system. In both systems, grain Fe and Zn levels were positively correlated. In the organic system, grain Mg concentration was correlated with Zn and Fe. As well, grain K concentration was correlated with Mn and Cu concentrations. In the conventional system, grain Mn was positively correlated with grain Fe and K concentrations. Negative correlations were detected between conventional grain Cu and Mn, and Mg and Fe concentrations (Table 3-4).

3.3.2 Soil microbial community

The non-metric multidimensional scaling (MRPP) analysis revealed that the soil microbial community grouped differently under organic versus conventional management ($P<0.001$) and between years; with the management effect having a stronger effect than years (data not shown). Cultivars exhibited no significant grouping patterns. There were significant grouping patterns in the management × cultivar interaction. Nevertheless, the individual comparisons suggest that all cultivars grown under the organic management system group differently than all cultivars grown under conventional management.

Three fungal PLFAs (16:1 w5c, 18:1 w9c and 20:1 w9c) were indicators for the organic system, with the fungal PLFA 20:1 w9c strongly associated with the organic system. Other strong indicator PLFAs for the organic system were the Gram+ bacterial PLFAs i14:0, i18:0 and i19:0 (Table 3-5).

In the organic system % AM fungi were negatively correlated with grain Zn and Fe concentrations and weed seeds, and positively correlated with grain Mn, Cu, K concentrations as well as grain yield (Table 3-6). PLFA diversity was positively correlated with grain Zn and Fe concentrations and weed seed yield, but negatively correlated with grain concentrations of Se, Mn, and Cu, and grain yield. Some indicator species for the organic system had weak positive correlations with Mn, Cu and K grain concentrations. The three fungal PLFAs were moderately correlated with grain Cu concentration.

In the conventional system % AM fungi was negatively correlated with grain concentrations of Zn and Fe, as well as grain protein content. Percent gram positive bacteria and actinomycetes had moderate negative correlations with grain Se and Cu concentrations, as well as grain and flour yield (Table 3-7). These biomarkers had moderate positive correlations with grain Mn, Mg and K concentrations. PLFA diversity was positively correlated with grain Mn, Mg and K concentrations, but had moderate negative correlations with grain Se and Cu concentrations, along with grain and flour yields.

3.4 Discussion

We originally hypothesized that the stress levels associated with organic management systems would result in higher levels of micronutrients in the grain, and specifically those with antioxidant properties. The organic system in the present study had higher grain Zn, Fe, Mg and K, but lower grain Se and Cu. In general, then, many of the studied micronutrients were greater in the organic system. However, only one of the three antioxidants studied (Zn, Se and Cu) was indeed present in the grain in greater concentrations in the organic system studied here. Selenium exhibited low concentrations in the wheat grain in this study when compared with other studies of similar design (Mäder et al. 2007; Zhao et al. 2009). The Se concentration of wheat cultivars has been reported to be more influenced by soil supply than genotype (Zhao et al. 2009). Some studies have reported some differences in wheat nutrient content grown organically versus conventionally (Ryan et al. 2004; Mäder et al. 2007; Turmel et al. 2009). However, the choice of management practices (e.g. tillage practices, crop rotation, fertility amendments) used within both of the systems under the specific local conditions will have an effect on soil fertility, and the subsequent grain nutrient concentration. Farmyard manure has been reported to provide a sustained supply of Cu and Zn to cropping systems, increasing yields and improving wheat Cu and Zn uptake over fallow for at least three years following manure application (Mishra et al. 2006). Ryan et al. (2004) reported that organic systems increased wheat grain Cu, N and Zn and decreased grain Fe and Mn, but concluded that differences in mineral contents were due to specific management practices chosen by producers, not from the overall management system. Turmel et al. (2009) concluded that differences in mineral content of wheat grown organically and conventionally was dependent on crop rotation. Decreased grain yield, and possibly smaller grain size, may, in part, account for increased grain nutrient concentration in the present organic system. However, the use of composted manure in the organic system did appear to supply nutrients for improved levels of grain nutrient concentrations.

We further hypothesized that western Canadian historic hard red spring cultivars would have higher mineral content than modern cultivars, especially in organic systems; and that those organic systems would have a more diverse microbial community structure. Significant interaction effects of management × cultivar indicate that the choice of wheat cultivar to maximize grain micronutrient level is dependent on management system. Glenlea grown organically had the highest grain nutrient levels compared to cultivars grown either organically or conventionally. Glenlea was the only Canadian extra strong wheat grown in the trial. Glenlea is generally characterized as having medium protein content and stronger gluten than the other cultivars studied (McCallum and DePauw 2008). Recently, it was reported that the introduction of semi-dwarf high-yielding cultivars has coincided with a decrease in wheat grain Cu, Zn, Fe and Mg contents (Fan et al. 2008). However, our results suggest no trend to lower grain mineral concentrations in the modern, high-yielding red spring wheat cultivars in Western Canada. This result is similar to that of Murphy et al. (2008) who reported a neutral trend between year of release and grain mineral content of hard red spring wheat cultivars of the Pacific Northwest. Murphy et al. (2008) did report a decline in all minerals tested except Ca, in the soft white wheat where yield has been successfully increased through breeding (apparently at the expense of some quality characters). Canadian hard spring bread wheat breeding programs have emphasized grain quality and disease resistance over the last century. It is evident that this emphasis on elevated grain quality in the western Canadian hard red spring class has resulted in retention of micronutrient quality characters and not an erosion of this quality characteristic.

Negative relationships between grain yield and grain Se, Zn, Fe, Mg and P have been reported in bread wheat (White and Broadley 2009). In the organic system, grain Zn, Fe, Mn and Mg concentrations were negatively correlated with grain yield. However, in the conventional system only grain Zn and Mg concentrations had weak and moderate (respectively) negative associations with yield. In both the organic and conventional systems there was a positive relationship between grain Zn and Fe concentrations. Rawat et al. (2009) found wheat accessions with high Fe content also had high Zn content, leading the authors to hypothesize that the nutrients shared similar uptake, translocation and deposition mechanisms.

In the organic system of the present study, the presence of AM fungi appears to have improved the uptake of Mn and Cu, but had a detrimental effect on Zn uptake. The indicator species for the organic system were positively correlated with grain Mn and Cu concentrations. Specifically, the PLFA biomarkers for fungi were all moderately correlated to grain Cu concentration, indicating that soil fungi played a role in plant Cu fertility.

In both the organic and conventional systems, % AM fungi was negatively correlated with grain Zn and Fe concentrations. In the organic system, % AM fungi and weight of AM fungi were positively correlated with Mn and Cu concentrations of wheat grain, as well as grain yield. Mycorrhizae can increase plant uptake of a number of nutrients, including: N, P, K, Ca, Mg, S, Fe, Mn, Cu and Zn (Mohammad et al. 2003; Al-Karaki et al. 2004; Cruz et al. 2004; Ryan et al. 2004; Mohammad et al. 2005); however, where mycorrhizae are most beneficial is in the uptake of relatively immobile nutrients such as phosphorus, copper and zinc (Habte 2006).

Phospholipid fatty acid diversity was positively correlated with grain concentration of some nutrients in both the organic and conventional systems, but differing nutrients in the two systems. Diversity was also negatively correlated with some grain mineral concentrations. In both systems, diversity was negatively correlated with grain Se and Cu concentrations, as well as grain yield.

The soil microbial community structure was different under the two management systems. The management practices that differed between the organic and conventional systems (crop rotation, along with fertility, pest management and tillage regimes) can all affect soil microbes, so we expected to see differences between the community structures of the two systems. Differences between organic and conventional management systems have been previously reported (Bossio et al. 1998; Lundquist et al. 1999). Differences are generally expected between microbial communities of organic and conventional cropping systems, and instances of no significant differences have been attributed to overriding effects of soil type and/or time of sampling (Wander et al. 1995; Bossio et al. 1998; Girvan et al. 2003).

All but one of the indicator species of PLFAs were indicators for the organic system. The three fungal PLFA biomarkers found in the soil were biomarkers for the organic cropping system, including biomarker 16:1 w5c, which is used as a biomarker for AM fungi. Mycorrhizal potential and actual colonization has been reported to be greater in grasslands, organic and low-input systems versus conventional systems (Mäder et al. 2000; Entz et al. 2004; Oehl et al. 2004). This is largely attributed to the fact that the application of phosphorus fertilizers, even at low rates, decreases root colonization of mycorrhizal fungi (Mäder et al. 2000; Ryan et al. 2004).

3.5 Conclusions

The organic system in the present study had higher grain Zn, Fe, Mg and K, but lower grain Se and Cu concentrations. In general, then, many of the studied micronutrients were greater in the organic system. However, only one of the three antioxidants studied (Zn, Se and Cu) was indeed present in the grain in greater concentrations in the organic system studied here. Wheat cultivar choice appears to be important for maximizing grain nutrient levels, and varies depending on the management system. It is evident that the emphasis on elevated grain quality in the western Canadian hard red spring class has resulted in the retention of micronutrient quality characters and not an erosion of this quality characteristic. The organic system had higher levels of fungi in the soil, including AM fungi, and these fungi biomarkers appeared to play a role in grain Cu concentration.

With elevated levels of micronutrients seemingly a component of both organic management practices and the general hard red spring breeding effort in western Canada, it is evident that both the agronomic system and breeding efforts in this region may lead to future increases.

Organic and conventional management systems have different soil microbial communities, and these communities can play a role in soil fertility and final grain nutritional content. However, individual practices within the management systems have an effect on the fertility status of the system. This study focused on the effect of Canadian hard spring wheat cultivar choice on soil microbial communities and crop nutritional quality within organic and conventional systems in the black soil zone of the northern Great Plains. Further studies are required to determine the impact of other agronomic cropping practices and to identify best management practices within organic and conventional systems for soil fertility and final crop quality.

It has been mentioned throughout the literature that increasing micronutrient levels in grain is but a small component of improving health outcomes for the many people in both the developed and developing world suffering nutrient deficiencies (Cordain et al. 2005). Strategies such as poverty alleviation, improved food transport channels, lessening of war, less dependence on processed foods and a greater reliance on dietary food diversity are beyond the scope of an agricultural study. Nevertheless, the results of the present study suggest that nutritional advances in the micronutrient content of wheat can be made through the choice of management system and through plant breeding. Such advances do not necessarily have to come at the expense of elevated or stable grain yield.

3.6 Summary

Micronutrient deficiencies in the diet of many people are common and wheat is a staple food crop, providing a carbohydrate and micronutrient source to a large percentage of our population. We conducted a field study to compare five Canadian red spring wheat cultivars (released over the last century) grown under organic and conventional management systems for yield, grain nutrient concentration, and soil phospholipid fatty acid (PLFA) profile. The organic system had higher grain Zn, Fe, Mg and K levels, but lower Se and Cu levels. In general, then, many of the studied micronutrients were greater in the organic system. There was no trend in the results to suggest that modern western Canadian hard red spring cultivars have lower grain micronutrient content than historical cultivars. Wheat cultivar choice appears to be important for maximizing grain nutrient levels, and varies depending on the management system. It is evident that the emphasis on elevated grain quality in the western Canadian hard red spring class has resulted in the retention of micronutrient quality characters. Three fungal PLFAs were indicators for the organic system, and all three of these indicators were positively correlated with grain Cu concentration. The organic system had higher levels of fungi in the soil, including arbuscular mycorrhizal fungi. Elevated levels of micronutrients are seemingly a component of both organic management practices and the general hard red spring breeding effort in and for the black soil zone of the northern Great Plains. It is evident that both the agronomic system and breeding strategies in this region can be exploited for future increases in grain micronutrient concentration.

3.7 Tables and Figures

Table 3-1. Summary of some characteristics of five wheat cultivars grown in experiment.

	Year of registration	Wheat class[z]	Maturity[y]	Height (cm)[x]	Parentage
Marquis	1910	CWRS	2	113	Red Fife x Hard Red Calcutta
Park	1963	CWRS	-2	91	(Mida x Cadet) x Thatcher
Glenlea	1972	CWES	0	-	(Pembina x Bage) x CB100
AC Elsa	1996	CWRS	0	89	BW90 x Laura
AC Superb	2000	CWRS	1	85	Grandin*2 x AC Domain

[z] CWRS: Canadian Western Hard Red Spring Wheat, CWES: Canadian Western Extra Strong Wheat

[y] Compared to AC Barrie: 106 days to maturity. Source: (see Nelson et al. in press)

[x] Height information taken from cultivar release information (see Nelson et al. in press)

Table 3-2. Soil properties for 0-15cm depth soil samples at the organic and conventional sites in the 2005-2007 growing seasons, prior to seeding in Edmonton, AB, Canada.

Year	NO_3 *(kg ha^{-1})*	P *(kg ha^{-1})*	K *(kg ha^{-1})*	SO_4 *(kg ha^{-1})*	Cu *(ppm)*	Mn *(ppm)*	Zn *(ppm)*	Fe *(ppm)*	Mg *(ppm)*	pH	Electrical conductivity *(dS m^{-1})*	Organic matter *(%)*
						Organic						
2005	199	260	1582	>90	-	-	-	-	-	6.1	0.91	10.3
2006	227	262	1581	>85	0.83	13.8	8.42	125	574	6.3	0.83	12.9
2007	56	83	533	16	1.23	14	6.61	141	2060	6.4	0.5	14.6
						Conventional						
2005	272	192	1462	>90	-	-	-	-	-	7.3	0.99	7.2
2006	252	213	1352	60	0.7	12.9	8.17	115	625	5.9	0.69	12.8
2007	41	>134	965	21	0.69	10.9	7.23	107	633	6.6	0.44	12.5

Table 3-3. Yields, weed seed mass and grain nutrient content for wheat grown organically and conventionally in Edmonton, AB in 2005, 2006 and 2007.[z]

Cultivar (YOR[y])	Weed mass *(kg ha^{-1})*	Yield *(t ha^{-1})*	Flour yield *(%)*	Se *(μg g^{-1})*	Cu *(ppm)*	Mn *(ppm)*	Zn *(ppm)*	Fe *(ppm)*	Mg *(ppm)*	K *(ppm)*
Organic										
Marquis (1910)	346	2.38	69	0.020	2.83	29.4	49.2	56.5	1352	3110
Park (1963)	294	2.65	71	0.021	2.75	29.4	48.0	53.8	1375	2989
Glenlea (1972)	230	2.78	69	0.025	4.02	35.4	56.0	63.5	1390	3443
AC Elsa (1996)	380	2.80	72	0.020	2.83	29.0	49.1	57.3	1278	3296
AC Superb (2000)	355	3.11	70	0.028	3.02	33.7	46.6	61.3	1376	3259
F $test_{cultivar}$	***	***	***	*	***	***	*	***	**	***
$SE_{cultivar}$	112.9	0.796	1.0	0.0050	0.469	4.98	6.73	5.02	62.2	173.6
Conventional										
Marquis (1910)	47	4.04	71	0.117	4.00	32.6	46.3	47.48	1299	2886
Park (1963)	46	4.66	72	0.115	4.50	31.9	44.0	43.39	1306	2770
Glenlea (1972)	41	5.57	73	0.125	4.02	31.3	39.9	47.42	1171	3101
AC Elsa (1996)	46	5.09	74	0.145	4.99	31.1	44.2	50.72	1285	2995
AC Superb (2000)	50	5.73	74	0.151	3.64	33.6	37.2	45.73	1289	3296
F $test_{cultivar}$	ns	***	***	ns	ns	ns	***	**	***	***
$SE_{cultivar}$	22.7	0.421	0.6	0.0627	0.709	3.81	1.26	4.00	61.5	78.8
Management System Main Effect										
Organic	321	2.74	70	0.022	3.07	31.3	49.6	58.3	1353	3218
Conventional	46	5.00	73	0.131	4.22	32.1	42.3	46.9	1270	3009
F $test_{management}$	***	***	***	***	***	ns	***	***	***	***
$SE_{management}$	52.9	0.401	0.6	0.0336	0.492	3.89	3.43	3.51	35.1	90.9
Combined Analyses										
F $test_{cultivar}$	***	***	*	ns	ns	***	***	***	**	***
$SE_{cultivar}$	57.6	0.467	0.8	0.0359	0.523	3.93	3.63	3.63	44.2	97.1
F $test_{m*c}$	***	**	ns	ns	**	**	***	***	***	***

[z]ns= not significant ($P \geq 0.10$), * significant at $P<0.10$, ** significant at $P<0.05$, *** significant at $P<0.01$, SE=standard error

[y] Year of release

Table 3-4. Pearson correlation coefficients of grain nutrient content, productivity and quality measures on five wheat cultivars grown organically (above the diagonal line) and conventionally (below the diagonal line) in Edmonton, AB in 2005-2007.[z]

	Se	Zn	Fe	Mn	Cu	Mg	K	Yield	Grain protein	Flour yield
Se		-	-	0.40	-	-	-	-	-	-
Zn	-0.30		0.72	0.28	-	0.74	-	-0.76	0.65	-0.63
Fe	-	0.48		0.28	-	0.59	-	-0.63	0.50	-0.45
Mn	-	0.31	0.50		0.27	0.41	0.63	-0.41	-	-
Cu	-	-	-	-0.48		-	0.49	0.33	-	-
Mg	-0.29	-	-0.45	-	-		-	-0.68	0.52	-0.66
K	-0.27	-	-	0.48	-0.32	-		-	-	-
Yield	0.37	-0.27	0.39	-	-	-0.51	0.47		-0.54	0.64
Grain protein	-	0.52	-	-	0.30	0.36	-	-0.30		-0.35
Flour yield	0.42	-	0.28	-	-	-0.39	0.42	0.70	-	

[Z] All correlation coefficients shown are significant at $P<0.05$; - indicates non-significance.

Table 3-5. Phospholipid fatty acid analysis (PLFA) indicator species associated with wheat rhizospheres grown organically or conventionally in Edmonton, AB in 2005 and 2006.

PLFA	Origin		Indicator value		Monte Carlo
		Mean	Conv.	Organic	p<0.05
i14:0	Gram +	35.4 (3.77)	6	74	0.0002
16:1 w5c	Fungi	50.8 (0.94)	45	55	0.0002
i17:0	Gram +	50.4 (0.78)	47	53	0.0002
a17:0	Gram +	50.3 (0.74)	48	52	0.0002
cyc17:0	Bacteria	50.4 (0.77)	53	47	0.0002
i18:0	Gram +	19.8 (3.82)	0	57	0.0002
18:1 w9c	Fungi	50.4 (0.77)	47	53	0.0002
i19:0	Gram +	27.0 (4.06)	6	48	0.0006
20:1 w9c	Fungi	44.8 (3.35)	0	45	0.0002

Table 3-6. Pearson correlation coefficients for grain measures and PLFA biomarkers and indicator species for five wheat cultivars grown organically in Edmonton, AB in 2005 and 2006.[z]

	Se	Zn	Fe	Mn	Cu	Mg	K	Grain yield	Weed seed	Flour yield
Gram - bacteria	-0.32	0.33	-	-0.45	-	-	-	-0.35	0.39	-
Gram + bacteria	-0.43	-	-	-	-	-	-	-	0.34	-
Actino-mycetes	-0.34	0.60	0.65	-0.55	-0.42	0.40	-0.54	-0.76	0.78	-0.43
AM Fungi	-	-0.44	-0.47	0.44	0.41	-	0.46	0.63	-0.57	0.38
Richness	-	0.33	0.38	-	-0.48	-	-	-0.59	0.62	-0.47
Evenness	-0.51	0.40	0.40	-0.45	-	-	-	-0.47	0.53	-
Diversity	-0.47	0.46	0.47	-0.34	-0.35	-	-	-0.62	0.67	-0.45
i14:0 (Gram +)[y]	-	-	-	0.35	-	-	-	0.34	-0.31	-
16:2 w5c (Fungi)	-	-	-	0.35	0.41	-	-	0.35	-0.32	-
i17:0 (Gram +)	-	-	-	0.35	0.41	-	-	0.32	-	-
a17:0 (Gram +)	-	-	-	0.35	0.47	-	-	0.33	-	-
i18:0 (Gram +)	-	-	-	-	-	-	-	-	-	-
18:1 w9c (Fungi)	-	-	-	-	0.43	-	-	-	-	-
i19:0 (Gram +)	-	-	-	-	0.46	-	0.36	-	-	-
20:1 w9c (Fungi)	-	-	-	-	0.66	-	-	-	-	-

[z] All correlation coefficients shown are significant at $P<0.05$; - indicates non-significance.
[y] Brackets following specific PLFAs give microbial group associated with the indicator PLFA.

Table 3-7. Pearson correlation coefficients for grain measures and PLFA biomarkers and indicator species for five wheat cultivars grown conventionally in Edmonton, AB in 2005 and 2006.[z]

	Se	Zn	Fe	Mn	Cu	Mg	K	Grain yield	Grain protein	Flour yield
Gram - bacteria	-	-0.37	-	-	-	-	0.32	-	-	-0.41
Gram + bacteria	-0.46	-	-	0.62	-0.37	0.53	0.40	-0.39	-	-0.59
Actinomycetes	-0.45	-	-0.31	0.50	-0.41	0.46	0.34	-0.45	-	-0.56
AM Fungi	-	-0.65	-0.34	-	-	-	-	-	-0.46	-
Richness	-0.52	-	-	0.67	-0.40	0.55	0.42	-0.42	-	-0.58
Evenness	-0.43	-	-	0.58	-0.36	0.47	0.46	-0.34	-	-0.48
Diversity	-0.48	-	-	0.63	-0.40	0.53	0.46	-0.40	-	-0.56
cyc17:0 (Bacteria)[y]	-	-	-	-	-	-	-	-	-	-

[z] All correlation coefficients shown are significant at P<0.05; - indicates non-significance.
[y] Brackets following specific PLFA gives microbial group associated with the indicator PLFA.

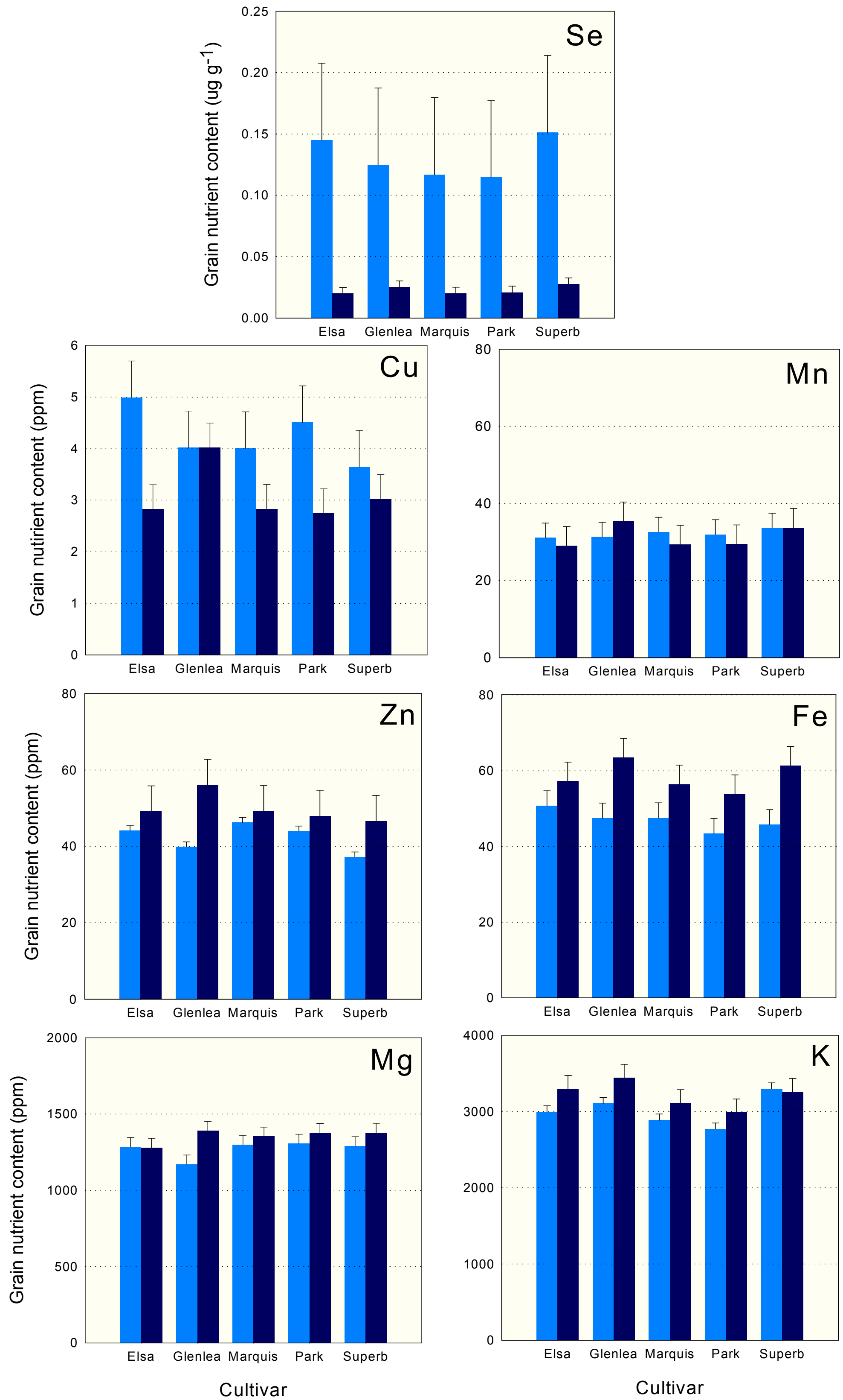

Figure 3-1. Grain Se, Cu, Mn, Zn, Fe, Mg and K content for five spring wheat cultivars grown organically (dark bars) and conventionally (light bars) in 2005-2007 in Edmonton, AB. Error bars show standard error for management × cultivar.

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4.0 Annual grain-broadleaf intercrops increase weed competitive ability in organically managed systems in the northern Great Plains[4]

4.1 Introduction

Organic agriculture is a legally defined form of sustainable agriculture based on holistic management of agroecosystems. The use of synthetic pesticides, fertilizers and genetically modified organisms (among other things) is prohibited in organic production (CGSB 2006). In Canada, 6.8% of all farms reported producing uncertified organic, transitional or certified organic products (Holmes and Macey 2009). Both organic and conventional cropping systems consist of a number of different management practices (chemical use, tillage, crop rotation and crop choice) used in combination. Production concerns for organic and conventional farmers are similar; however, the absence of inorganic fertilizers and pesticides in extensive organic systems in the Canadian Prairies generally leads to greater weed populations, higher tillage intensities, and lower soil nutrient levels (Entz et al. 2001; Snyder and Spaner 2010). Weed competition plays a role in reducing crop yields, and has been identified by farmers and researchers as a considerable threat to organic crop production (Bàrberi 2002; Degenhardt et al. 2005). Canadian organic farmers have also identified the maintenance and improvement of soil fertility as a production constraint and research need (Organic Agriculture Centre of Canada 2008; Degenhardt et al. 2005).

Intercropping, or crop polyculture, is the practice of growing two or more crops at the same time in the same area (Vandermeer 1989). It has been identified as a possible management strategy to increase crop productivity and crop competitive ability against weeds, especially in organic (low-input) systems. Differences in the spatial or temporal requirements of light, water and nutrients of the component crop species can lead to enhanced use of resources and intercrop yields higher than monocultures of the same component crops (Willey 1979). Overyielding (land equivalent ratios >1) has been reported in annual intercrops under organic and low-input systems (Hauggaard-Nielsen et al. 2008; Szumigalski and Van Acker 2005).

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[4] *A version of this chapter has been submitted for publication. Nelson, A.G., Quideau, S., Frick, B. and Spaner, D. 2011. Crop Sci.*

Different crop species and cultivars have differing abilities to compete against weeds. A survey of commercial fields in Alberta reported that yield losses decrease from peas>canola>barley, both in the number of fields with significant yield losses due to weeds and in the average yield losses due to weeds (Harker 2001). A field study in Alberta compared intercrops of wheat with other spring cereals (oats, barley and triticale), and reported that mixtures containing barley were the most weed suppressive (Kaut et al. 2008). A review of intercrops where all component crops are main crops (yield of all crops are of interest to producer) found weed biomass to be reduced compared to all sole component crops in 12 cases, or intermediate between all component crops in 10 cases, out of a total of 24 cases (Liebman and Dyck 1993). A study in the Canadian prairies found wheat-canola, canola-pea and wheat-canola-pea intercrops had weed suppression above the sole crop treatments (Szumigalski and Van Acker 2005). Other studies have found intercrops to suppress weeds over monocultures (Hauggaard-Nielsen et al. 2008; Poggio 2005). Of these studies, only Kaut et al. (2008) studied mixtures in organic systems and they did not incorporate broad leaf crops.

Soil microbes and soil microbial diversity can affect soil fertility and impart resistance and resililance to disturbance and stress within agroecosystems (Brussaard et al. 2007; Brussaard et al. 2004). Because most microbes are heterotrophic, soil organic matter content and the type and amount of organic materials added to the soil are two critical soil factors affecting microbial diversity (Shannon et al. 2002).

Differential effects of plant species on soil microbial communities may be caused by differences in plant material composition and differences in plant root exudates. Crop species may or may not have differing effects on soil microbial communities, depending on environmental and plant factors (Grayston et al. 1998; Koo et al. 2006). Differences in the soil microbial community structure and function among the rhizospheres of monocropped wheat (*Triticum aestivum* L.) and forage species such as ryegrass (*Lolium perenne* L.) or bentgrass (*Agrostis capillaries* L.) have been reported (Grayston et al. 1998). Other studies have little to no difference among the rhizospheres of various crop species (Song et al. 2007). However, soil microbial diversity has been reported to increase with increased above-ground plant diversity (Garbeva et al. 2006; Song et al. 2007).

Intercropping research where all component crops are considered main crop species and harvested for grain is limited in the Canadian prairies. As well, little research has been carried out on complex (three- or four-crop) annual intercropping systems in the

Canadian prairies (Szumigalski and Van Acker 2005). No such studies exist in organic systems in western Canada.

In the present study, monocultures of spring wheat, barley, canola and peas, along with all 2-, 3- and 4-crop intercrop combinations with wheat were investigated to test the hypothesis that the intercrops could improve productivity and weed suppression over monocultures of the component crops under both organic and conventional conditions. We also wished to test the hypotheses that soil microbial structure and diversity would differ under organic and conventional management regimes and that intercrops of common annual crops grown in the Canadian prairies would have higher microbial diversity than annual crop monocultures.

4.2 Materials and Methods

A field experiment was conducted in 2006 and 2007 at paired organically and conventionally managed sites in Edmonton, Alberta (55°34´N, 113°31´W) and on a certified organic farm near Camrose, Alberta (52°52´N, 112°56´W) to compare annual crop monocultures and mixtures. The conventional site was planted in Edmonton 500 m away from the organic site on the same soil type (Orthic Black Chernozem) to compare the Edmonton organic system to a conventional system with weeds controlled through herbicides. There were 11 treatments in total, consisting of monocultures of wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare* L.), canola (*Brassica napus* L.) and peas (*Pisum sativum* L.); as well as all crop mixture combinations containing wheat grown in a four-replicated randomized complete block design. Barley and pea cultivars were Seebe and Nitouche, respectively. We planted non-transgenic herbicide tolerant cultivars of wheat (CDC Imagine) and canola (Cougar CL) at the two Edmonton sites to allow for chemical weed control at the conventional site in the crop combinations of wheat, canola and peas. The organically managed site in Edmonton is located at the University of Alberta Research Farm and is not certified organic; in all other ways it conforms to organic certification standards. At the certified organic farm site near Camrose, conventional cultivars of wheat and canola (Park wheat and 46A65 canola) were grown.

Plot dimensions were 5 m by 2.8 m, with 12 rows spaced 23 cm apart. Plots were seeded with a no-till double disk drill (Fabro Enterprises Ltd., Swift Current, SK, Canada). Monocultures were sown at recommended target plant populations for the four component crops to achieve optimal monocultures for comparison with the polycultures (Vandermeer 1989). Wheat and barley were sown for a target plant population of 300 seeds m^{-2}, canola at 90 seeds m^{-2} and peas at 75 seeds m^{-2} in the monocrops. The intercrops were seeded at plant density relative to the number of crops in the intercrop (i.e. if the seeding rates of the monocrops are considered 100% for each crop, the component crops of the intercrops were planted at 50%, 33% and 25% of their target plant populations for intercrops with 2, 3 and 4 component crops, respectively). Wheat, barley and peas were seeded together at a depth of 5 cm and canola was seeded over top, in the same rows at a shallower depth. Trials were seeded in May. Peas were not inoculated with *Rhizobia*, as one goal of the experiment was to investigate the effect of intercrops on soil microbial communities. Seed treatments were not used on the crops in the conventional system.

At the conventional Edmonton site, the land was fertilized with 112 kg ha^{-1} of N banded in the form of urea (46-0-0) every fall. Thirty-six kg ha^{-1} of 11-52-0 was also banded with the seed for 4 kg ha^{-1} of N and 19 kg ha^{-1} of P_2O_5 as urea and ammonium phosphate. The organic land had compost (comprised of dairy manure, sawdust, wood chips and straw) applied each year for the 5 years prior to 2005 at a rate of 50-62 t ha^{-1}. No compost was added during the trial years of 2005 to 2007. In Edmonton, the treatments wheat (W), canola(C), pea (P), wheat-canola (WC), wheat-pea (WP), wheat-canola-pea (WCP) at the conventional site were sprayed with Solo ® at 20g a.e. ha^{-1} with 0.5% v/v Merge ® adjuvant. The barley (B) and wheat-barley (WB) treatments were sprayed with Dyvel ®, a combination of Dicamba (demethylamine salt) and MCPA (potassium salt) at 104 g a.e. ha^{-1} and 415 g a.e. ha^{-1}, respectively. No in-crop chemical weed control was carried out on the Edmonton organic site, or the Camrose organic site. The Camrose organic site had no external fertilizer inputs, but had a legume plowdown crop grown the year prior to plot establishment.

One-half of the plots were used to collect all samples within the growing season, and the other half was left intact for harvest. Crop emergence counts were taken two weeks after seeding in two randomly chosen 50 cm row segments within each plot. Two biomass samples were taken from each plot approximately 70 days after seeding from a 0.23 m^{-2} area (0.5m by 0.45m, consisting of 50 cm segments of two crop rows and two inter-row areas). The crops and weeds within the sampling area were collected in separate bags for each of the crop species and one bag for all weeds present in the plot. Samples were dried at 40°C for a minimum of 48 hours and weighed. Biomass samples taken again at harvest were used to determine yield of the component crops, as well as the weed biomass present at harvest. Crop plants were collected in paper bags, dried at 40°C for a minimum of 72 hours, then threshed with stationary threshers.

A Wintersteiger plot combine was used to harvest the intact half of the plots, and grain from this half of the plot was collected for other analyses. The various crop grains collected from the combine were separated and cleaned using mechanical and manual means.

Soil samples to determine soil microbial community structure via phospholipid fatty acid analysis (PLFA) were taken approximately 60 days after seeding from the first two field replicates. Soil cores (5cm diameter) were taken directly below two randomly chosen wheat plants from each plot to a depth of 15cm (in monoculture plots, soil samples were taken over two crop plants). The soil cores were placed in sterile plastic bags and stored at -20°C until subsampling. Two grams of soil were subsampled from each soil core at the origin of root growth where roots were dense (to collect the rhizosphere soil) and freeze-dried.

Phospholipid fatty acids were extracted and analysed following the method outlined in Hannam et al. (2006). Briefly, fatty acids were extracted using a modified Bligh and Dyer extraction process. Phospholipid fatty acids were separated from other lipids on silicic acid columns (Agilent Technologies, Wilmington, DE), and then methylated using a mild acid methanolysis to form fatty acid methyl esters (FAMEs). The FAMEs were analyzed using an Agilent 6890 Series capillary gas chromatograph (Agilent Technologies, Wilmington, DE) with a 25 m Ultra 2 (5%-phenyl)-methylpolysiloxane column). The MIDI software was used for peak identification (MIDI, Inc., Newark, DE).). The X:YωZ nomenclature is used to designate fatty acids, with X indicating the total number of carbon atoms, Y indicating the number of double bonds, and Z indicating the position of the first double bond from the aliphatic (ω) end of the molecule. The suffix “c” refers to the cis geometry, “cyc” refers to cyclopropyl rings, and the prefixes “i”, “a”, and “Me” refer to iso, anteiso and mid-chain methyl branching.

4.2.1 Data analysis

Productivity of the intercrops was assessed using the land equivalent ratio (LER) for grain yields and crop biomass. The land equivalent ratio calculates the relative land area required of monoculture crops to achieve the same yield or biomass of the intercrop under the same conditions. The equation used to calculate LER was (Vandermeer 1989):

$$LER = I_a/M_a + I_b/M_b$$

where I is the intercrop yield, M is the monocrop yield and a and b are the component species of the intercrop. A LER greater than 1 indicates that the intercrop has greater land use efficiency than the monocultures. Land equivalency ratios were calculated for each intercrop plot, using mean monoculture grain or biomass yields across all replicates at a site as the denominators in the above equation, to give a conservative estimate of LER values (Vandermeer 1995). Relative weed biomass (RWB) is an indicator of an intercrop's ability to suppress weeds, and was calculated using the following equation:

$$RWB = Ib/(\Sigma Sb_{i\ \ldots n}/n)$$

Ib is weed biomass in the intercrop, $\Sigma Sb_{i\ \ldots n}$ is the sum of weed biomass within the sole crops of the component crops in the intercrop, and n is the number of component crops. A RWB less than 1 indicates possible synergistic weed suppression of the component crops of the intercrop. Ability to compete (AC) and ability to withstand competition (AWC) were used to measure the ability of a cropping treatment to suppress weeds and to tolerate competition from weeds, respectively (Szumigalski and Van Acker 2005). AC was calculated on the organic treatments with the equation:

$$AC = 100 - [(b_w/b_t)100]$$

with b_w being the weed biomass and b_t being the total crop and weed biomass. AWC was calculated with the equation (modified from Szumigalski and VanAcker (2005)):

$$AWC = (Cb_o/Cb_c)100$$

Cb_o is the crop biomass of the organic plots (no weed control during crop growth – representing a weedy system) and Cb_c is crop biomass of the conventional plots (weed control during crop growth – representing a relatively weed-free system). For AWC, the average crop biomass of the treatments from the conventional plots from all replicates at a site was used in the denominator of the equation. This index was only calculated in Edmonton where experiments were planted on conventionally managed land for comparison purposes.

Crop and weed biomass, AC and AWC were subjected to a preliminary analysis of variance using Proc GLM in SAS (SAS Inc. 2002) to obtain percent sums of squares breakdown and relative sources of variation on combined data. Environment (location-year), replication and their interactions were considered random, and cropping treatment was considered fixed. Separate analyses of variance for the Edmonton organic and conventional and Camrose organic sites were carried out using Proc MIXED. Cropping treatment was considered a fixed effect, while year, replication within year, and cropping treatment×year were considered random. Mean LER and RWB values of the cropping treatments were compared with a value of 1 in a one-tailed t-test using Proc TTEST in SAS. A T-test for each component crop in the intercrop treatments was used to compare the percent emerged component crops (of total intercrop plant population) to the percent of planted component crop ratios.

The structure of the microbial community (PLFAs) for the entire experiment, and for the two management systems separately was characterized with non-metric multidimensional scaling (NMS) ordination using PC-ORD (version 5, MjM Software Design). Only PLFAs previously reported to be associated with soil microbes were included in the ordination. Fatty acids present in less than 10% of the samples were omitted from the analysis. Specific biomarkers as defined by (DeGrood et al. 2005) were used to calculate the percent of total biomass as gram negative bacteria, gram positive bacteria, and actinomycetes (DeGrood et al. 2005). The PLFA marker 16:1w5 was used to indicate mycorrhizal fungi (Dalpé and Hamel, 2007). The PLFA data were arcsine square-root transformed prior to ordination, as is necessary for proportional data (McCune and Grace 2002). A Sorensen (Bray-Curtis) distance measurement was used in all ordinations. Biplots were used to show the relationship between weed and crop biomass, yield and PLFA ordination scores.

Significant differences between management system, year and cropping treatments were evaluated on the NMS analyses using a multi-response permutation procedure (MRPP) for the Edmonton sites only. Within MRPP analysis, T values are an indicator of separation between groups, with larger T values indicating greater separation, and A values indicate the homogeneity within groups (McCune and Grace, 2002). Indicator species analyses were used to evaluate the relationship between individual PLFAs and the two management systems.

4.3 Results

Average Edmonton organic grain yields (2178 kg ha^{-1}) were roughly one-half of the Edmonton conventional yield (4471 kg ha^{-1}) (Table 4-1). The canola and pea sole crops had significantly lower yields than the other cropping treatments at both organic sites; while canola yielded lower than the other cropping treatments at the conventional site, this (1541 kg ha^{-1}) represents an average canola yield for the region. At the organic sites some of the intercrops yielded more grain than the sole crops, while at the conventional site many were statistically similar or greater yielding (Table 4-1).

The wheat-barley-pea intercrop overyielded (land equivalent ratios > 1) compared to the monocrops for both organic locations, as well as the wheat-barley-canola-pea intercrop at the Camrose organic site (Table 4-2). At the Edmonton conventional site, all the intercrops that included barley (and the wheat-canola treatment) overyielded.

At both the Camrose and Edmonton sites, the cropping treatments containing barley had the highest levels of crop biomass 70 days after seeding, and the sole crops of canola and peas had the lowest levels of crop biomass (Table 4-3). The conventional site had similar results.

Average weed biomass 70 days after planting in the Edmonton organic system (148 g m^{-2}) was greater ($P<0.001$) than in the conventional system (24 g m^{-2})(Table 4-4). The weed biomass 70 days after planting was similarly affected by cropping treatment at the organically managed sites; cropping treatments containing barley, and the sole crop of wheat had the lowest weed biomass levels, followed by the intercrops wheat-canola, wheat-pea and wheat-canola-pea. Finally, the sole crops of canola and peas had the highest weed biomass levels. Weed biomass levels at harvest had similar patterns to the mid-season weed biomass levels (Table 4-5). The conventional site did not differ for weed biomass 70 days after planting or for weed seed yield at harvest for any cropping treatment (Tables 4-4 and 4-5). Relative weed biomass values were significantly less than 1 (indicating weed suppression of intercrops above that of the monoculture component crops) for a number of intercrop treatments at both organic sites (Table 4-6). The wheat-barley-canola-pea intercrop had relative weed biomass values <1 at all locations and management systems ($P<0.05$). The three-crop intercropping treatments (wheat-barley-canola, wheat-barley-pea and wheat-canola-pea) also exhibited weed suppression above the component crops on organic sites, with only wheat-barley-pea being non-significant in Camrose. Of the two-crop intercropping treatments (wheat-barley, wheat-canola and wheat-pea) only wheat-canola exhibited weed suppression over the monocrops at Camrose. The wheat-barley-canola, wheat-barley-pea and wheat-barley-canola-pea intercrops had lower weed biomass than the canola and pea sole crops (Table 4-4). None of the intercrop treatments at either location had higher weed biomass ($P<0.05$) than their component sole crops.

The crop ability to compete with weeds was different amongst the cropping treatments at the Edmonton organic site (Table 4-7). The ability to compete was lower in the pea (31%) and canola (24%) sole crops, and the wheat-pea (62%) and wheat-canola-pea (63%) intercrops (Table 4-7). The highest ability to compete value was exhibited by the barley sole crop (97%). Barley and wheat-barley-canola exhibited the highest ability to withstand competition (Table 4-7).

At emergence the plant community composition matched closely with the seeded crop ratios in most cases (Figure 4-1). Some exceptions were seen mainly in the emerged canola and pea plants in the organic sites, which may have had some effect on final crop yields in the organic systems. The percent of grain yield (by weight) represented by the component crops in the intercrop treatments was calculated to indicate the final species composition (Figure 4-2). Although relative seed size of the various component crops will affect these numbers (e.g. canola seed is smaller than wheat or barley seed), it is still informative to show the final composition of the crop yield. The final grain harvest was dominated by the cereals, wheat and barley, with very little of the harvest weight made up of canola or peas.

4.3.1 Soil microbial community

Total soil microbial biomass (sum of all microbial PLFAs) was not affected by management system or cropping treatments in this study. A three-dimensional NMS ordination was produced from the samples collected at Edmonton with a final stress of 13.28 after 155 iterations (Figure 4-3). Axis one, two and three of the ordination explained 48%, 27% and 14% of the total variation, respectively. Community structure grouped according to year and management system. At Edmonton the microbial community grouped by management system more strongly than by year (Table 4-8). Cropping treatments did not group differently (P=0.59, A=-0.004).

Indicator species analysis for the Edmonton sites revealed that some specific PLFAs were associated more closely with a given management system (Table 4-9). The fungal indicators PLFAs 18:3ω6,9,12c and 18:2ω6,9c, as well as the Gram positive PLFA i18:0 were associated with conventional management. The PLFA 10Me16:0 (actinomycetes), and in particular the Gram negative biomarker 18:1ω5c were associated with organic management.

4.4 Discussion

Some intercrops we tested here in organic systems in the northern Great Plains have the ability to overyield compared to their component monocrops. Land equivalent ratios for grain yield greater than one were achieved for wheat-barley-pea and wheat-barley-canola-pea mixtures in organically managed systems in this study. Overyielding occurred despite the pea seed not being inoculated with Rhizobium bacteria prior to seeding, possibly lowering the benefits of combining a leguminous crop with non-leguminous plants. Intercropping benefits in this study were largely attributed to the ability of the intercrops to suppress weeds, as weed pressure was high at the two organic locations. The pea and canola crops competed poorly with weeds, leading to low sole crop yields of these crops. Barley has been reported to be more competitive than wheat (Cousens 1996) as well as the other crops in this study, in part because of its early germination and growth (Cousens 1996; Hauggaard-Nielsen et al. 2006). A survey of barley, canola and pea fields in Alberta found yield losses due to weeds to average 29%, 40% and 46%, respectively (Harker 2001). The barley crop dominated the grain harvest in the intercrops where it was present. We previously reported Seebe barley to be an extremely strong competitor with weeds and it is for this reason that it was chosen for this study (Mason et al. 2007). It is evident, however, that in choosing appropriate blends for crop mixtures in organic systems, it will be imperative to determine the relative competitive ability of the various crops and cultivars in the blend.

This experiment demonstrates that intercropping a competitive species, such as wheat or barley, with a less competitive crop, such as peas or canola, can result in intermediate weed suppression levels between the component crops. In environments with high weed pressure (such as some organic systems), intercropping systems that combine crops of varying competitiveness can protect against major yield losses. However, the cropping system practices and the environment under which the systems operate will affect the performance of the various intercrops. Further studies must be conducted to determine optimum relative plant densities of the component crops in an intercrop, as well as the economic performance of the systems. The use of an extremely competitive cultivar such as Seebe barley in the present study resulted in a dominance of this crop in the final yield and, in part, negated the economic benefit of the intercrop. As part of the evaluation of intercrop performance when multiple crops are harvested for grain yield, it is important to consider the relative economic value of the component crops (Vandermeer 1989).

The most complex intercropping treatment, wheat-barley-canola-pea, had weed suppression above that of component crops at both organic sites and at the conventional site, as measured by mean relative weed biomass. The three- and two-crop intercropping treatments also exhibited weed suppression above the component crops, in fewer instances and with decreasing intercrop complexity. A greenhouse study reported an increase in weed suppression with increased crop richness to a maximum of seven or eight crop species (Szumigalski and VanAcker 2006).

Management system and year affected the composition of the soil microbial community. Organic and conventional systems have been reported to have differing microbial communities (Bossio et al. 1998; Lundquist et al. 1999). Inherent variation in soil conditions (e.g. temperature and moisture) from year to year at the time of sampling can affect soil microbes and lead to differences in microbial community structure (Campbell et al. 1999).

Fungal PLFA indicators were associated with conventional management in this study. Use of tillage can negatively affect fungi, physically breaking hyphae. It is generally believed that zero tillage systems are fungal dominated, while conventional tillage systems, a common practice for weed control on organic farms on the Canadian Prairies, are bacterial dominated (Kladivko 2001). Tillage decreases the fungal component of a soil microbial community for at least two weeks following an operation (Jackson et al. 2003). In a previous study (Chapters 2.0 and 3.0) the presence of weeds was negatively correlated with soil fungal presence. Non-mycorrhizal weeds such as redroot pigweed (*Amaranthus retroflexus* L.), lamb's quarters (*Chenopodium album* L.), and smartweed (*Polygonum lapathifolium* L.) (Vatovec et al. 2005) were present in the organic system, and can lower mycorrhizal colonization of the crop (Stejskalova 1990).

Phospholipid fatty acid profiles were not affected by cropping treatment. We expected that the intercrops, with a greater diversity of plants and sources of organic matter, would have a greater diversity of soil microbes. However, studies on the effect of crop type on the composition of soil microbial communities report varying treatment effects (Marschner et al. 2001). Song et al. (2007) found the impact of annual intercrops on soil microbial communities was not apparent until the second growing season, and became more pronounced in the third field season. With this study, annual intercrops were grown for one year, and soil microbial community measured during that growing season. There may not have been sufficient time for the intercrops to affect the soil microbial community. The intercrops in the study were dominated by barley, and to a lesser degree, wheat, so it is also possible that these dominant crops had a greater influence on the microbial community composition than the lesser crops.

4.5 Conclusions

Complex intercrops can improve crop competitive ability against weeds, especially in an organic system, but also showed an ability to overyield in a conventional system where weeds are controlled through herbicides. The inclusion of canola into organic intercropping systems is unlikely as the majority of the canola seed in Canada is genetically modified or contaminated with genetically modified seed. Peas have promise as a component crop of an organic intercrop system, but a better balance must be struck amongst crops and cultivars in intercrop design. Further research is required to establish recommendations on seeding rates and cultivar choice of component crops in intercrops to ensure benefits of intercrops are maximized (weed suppression, economic yield, etc.). The soil microbial communities differed between the management systems, however, intercropping effects on soil microbial communities were not found in this study. The complex interactions between crop and weed plants, cropping inputs, agronomic practices and the soil microbial communities must be teased out to gain a deeper understanding of how intercropping systems affect soil microbes.

4.6 Summary

Intercropping has been identified as a possible management strategy to increase crop productivity and improve yield stability, especially in organic (low-input) systems. Monocultures of spring wheat, barley, canola and peas, along with all 2-, 3- and 4-crop intercrop combinations with wheat were grown at two organic and one conventionally managed site in northern Alberta, Canada in 2006 and 2007. Cropping treatment and management effects on crop biomass production, grain yield, weed biomass and crop competitiveness against weeds, as well as soil microbial structure [measured by phospholipid fatty acid (PLFA) analysis at Edmonton site only] were determined. Intercrop treatments had land equivalent ratios (LER) greater than one (indicating overyielding compared to component crops) in most instances. The most complex intercropping treatment, wheat-barley-canola-pea, had weed suppression above that of component crops at both organic sites and at the conventional site, as measured by mean relative weed biomass. The two- and three-crop intercropping treatments also exhibited weed suppression above the component crops, in fewer instances and with decreasing intercrop complexity. Complex intercrops can improve crop competitive ability against weeds, especially in an organic system, but also exhibited an ability to overyield in a conventional system where weeds were controlled by herbicides. The cropping treatments containing barley had the lowest levels of weed biomass. In Edmonton, the barley monocrops had the highest ability to compete against weeds (97%), and had higher ability to compete than the canola and pea monocrops (canola 24%, peas 31%). At the Edmonton site, soil microbial community structure was influenced by management system and year, but not by cropping treatment. Further research is required to establish recommendations on seeding rates and cultivar choice of component crops in intercrops to ensure benefits of intercrops are maximized (weed suppression, economic yield, etc.).

4.7 Tables and Figures

Table 4-1. Crop grain yield least-square means for sole crops and 7 intercropping treatments at the Camrose and Edmonton conventional and organic locations in 2006 and 2007 (n=8).[z]

Cropping Treatment	Camrose Organic	Edmonton Organic	Edmonton Conventional
		(kg ha^{-2})	
Wheat (W)	2065	2571	4434
Barley (B)	2661	2874	4824
Canola (C)	206	239	1541
Pea (P)	109	162	3397
Wheat-Barley (WB)	2369	3134	5162
Wheat-Canola (WC)	1415	2084	5049
Wheat-Pea (WP)	1288	2293	4712
Wheat-Barley-Canola (WBC)	1981	2739	5233
Wheat-Barley-Pea (WBP)	2191	3085	5215
Wheat-Canola-Pea (WCP)	1478	1822	4112
Wheat-Barley-Canola-Pea (WBCP)	2025	2959	5506
Mean	**1617**	**2178**	**4471**
F $test_{intercrop}$	***	**	***
SE of $diff_{intercrop}$[y]	301	732	544

[z]ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01

[y] Standard error of the difference of two lsmeans.

Table 4-2. Mean grain yield Land Equivilent Ratio (LER) values for 7 intercropping treatments grown at Edmonton and Camrose in 2006 and 2007, and results of one-sided t-test (n=8).[z]

Cropping Treatment	Camrose Organic	Edmonton Organic	Edmonton Conventional
Wheat (W)	1 (2065 *kg ha*$^{-1}$)	1 (2571 *kg ha*$^{-1}$)	1 (4434 *kg ha*$^{-1}$)
Barley (B)	1 (2661 *kg ha*$^{-1}$)	1 (2874 *kg ha*$^{-1}$)	1 (4824 *kg ha*$^{-1}$)
Canola (C)	1 (206 *kg ha*$^{-1}$)	1 (239 *kg ha*$^{-1}$)	1 (1541 *kg ha*$^{-1}$)
Pea (P)	1 (109 *kg ha*$^{-1}$)	1 (162 *kg ha*$^{-1}$)	1 (3397 *kg ha*$^{-1}$)
Wheat-Barley (WB)	0.98 (0.06)	1.15 (0.20)	1.09 (0.05)*
Wheat-Canola (WC)	1.13 (0.22)	0.82 (0.14)	1.17 (0.03)*
Wheat-Pea (WP)	1.26 (0.22)	1.64 (0.86)	1.09 (0.05)
Wheat-Barley-Canola (WBC)	0.99 (0.11)	0.89 (0.10)	1.10 (0.03)*
Wheat-Barley-Pea (WBP)	1.22 (0.09)*	1.39 (0.20)*	1.13 (0.02)*
Wheat-Canola-Pea (WCP)	1.74 (0.41)	1.93 (0.73)	0.99 (0.05)
Wheat-Barley-Canola-Pea (WBCP)	1.27 (0.14)*	1.13 (0.15)	1.17 (0.04)*

[z] Treatment LERs significantly greater than 1 at P<0.05 (one-sided t-test) indicated by *. Values in brackets are the monocrop yield for the monocrop treatments, and the standard errors of mean for the intercrop treatments.

Table 4-3. Crop biomass (70 days after planting) least-square means for sole crops and 7 intercropping treatments at the Camrose and Edmonton conventional and organic locations in 2006 and 2007 (n=8).[z]

Cropping Treatment	Camrose Organic	Edmonton Organic	Edmonton Conventional
		(g m^{-2})	
Wheat (W)	511	518	818
Barley (B)	562	746	1077
Canola (C)	103	120	509
Pea (P)	133	216	480
Wheat-Barley (WB)	479	681	1076
Wheat-Canola (WC)	406	479	845
Wheat-Pea (WP)	347	395	804
Wheat-Barley-Canola (WBC)	457	615	913
Wheat-Barley-Pea (WBP)	458	595	1039
Wheat-Canola-Pea (WCP)	361	394	722
Wheat-Barley-Canola-Pea (WBCP)	486	538	901
Mean	**391**	**482**	**835**
F $test_{intercrop}$	***	**	***
SE of diff $_{intercrop}$ [y]	84	125	107

[z] ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01
[y] Standard error of the difference of two lsmeans.

Table 4-4. Weed biomass (70 days after planting) least-square means for the sole crop and 7 intercropping treatments at the Camrose and Edmonton conventional and organic locations in 2006 and 2007 (n=8).[z]

Cropping treatment	Camrose Organic	Edmonton Organic	Edmonton Conventional
		($g\ m^{-2}$)	
Wheat (W)	63	130	38
Barley (B)	40	11	7
Canola (C)	295	353	18
Pea (P)	232	383	60
Wheat-Barley (WB)	63	51	9
Wheat-Canola (WC)	140	142	22
Wheat-Pea (WP)	167	191	44
Wheat-Barley-Canola (WBC)	70	51	5
Wheat-Barley-Pea (WBP)	93	61	5
Wheat-Canola-Pea (WCP)	116	187	56
Wheat-Barley-Canola-Pea (WBCP)	88	67	5
Mean	**124**	**148**	**24**
F $test_{intercrop}$	***	***	ns
SE of $diff_{intercrop}$ [y]	51	49	28

[z]ns = not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01.
[y] Standard error of the difference of two lsmeans.

Table 4-5. Harvest weed biomass least-square means for the sole crop and 7 intercropping treatments at the Camrose and Edmonton conventional and organic locations in 2006 and 2007 (n=8).[z]

Cropping treatments	Camrose Organic	Edmonton Organic	Edmonton Conventional
		(g m^{-2})	
Wheat (W)	66	215	97
Barley (B)	25	80	12
Canola (C)	244	868	57
Pea (P)	234	627	255
Wheat-Barley (WB)	75	80	14
Wheat-Canola (WC)	112	357	44
Wheat-Pea (WP)	135	271	67
Wheat-Barley-Canola (WBC)	57	123	5
Wheat-Barley-Pea (WBP)	88	117	11
Wheat-Canola-Pea (WCP)	133	421	72
Wheat-Barley-Canola-Pea (WBCP)	77	201	10
Mean	**113**	**305**	**59**
F $test_{intercrop}$	***	***	ns
SE of $diff_{intercrop}$ [y]	39	120	86

[z] ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01.
[y] Standard error of the difference of two lsmeans.

Table 4-6. Mean relative weed biomass values for 7 intercropping treatments grown at Edmonton and Camrose in 2006 and 2007, and results of one-sided t-test (n=8).[z]

Cropping treatments	Camrose Organic	Edmonton Organic	Edmonton Conventional
Wheat (W)	1 (66 *kg ha*$^{-1}$)	1 (215 *kg ha*$^{-1}$)	1 (97 *kg ha*$^{-1}$)
Barley (B)	1 (25 *kg ha*$^{-1}$)	1 (80 *kg ha*$^{-1}$)	1 (12 *kg ha*$^{-1}$)
Canola (C)	1 (244 *kg ha*$^{-1}$)	1 (868 *kg ha*$^{-1}$)	1 (57 *kg ha*$^{-1}$)
Pea (P)	1 (234 *kg ha*$^{-1}$)	1 (627 *kg ha*$^{-1}$)	1 (255 *kg ha*$^{-1}$)
Wheat-Barley (WB)	1.24 (0.20)	0.75 (0.19)	3.15 (1.01)
Wheat-Canola (WC)	0.81 (0.11)	0.62 (0.15)*	2.44 (1.86)
Wheat-Pea (WP)	1.13 (0.11)	0.85 (0.17)	1.08 (0.50)
Wheat-Barley-Canola (WBC)	0.56 (0.21)*	0.32 (0.13) *	1.54 (1.45)
Wheat-Barley-Pea (WBP)	0.87 (0.20)	0.37 (0.10) *	0.10 (0.06) *
Wheat-Canola-Pea (WCP)	0.64 (0.14)*	0.67 (0.14)*	1.41 (0.91)
Wheat-Barley-Canola-Pea (WBCP)	0.60 (0.14) *	0.30 (0.07) *	0.13 (0.07) *

[Z] Treatment LERs significantly different from 1 at P<0.05 (one-sided t-test) indicated by *. Values in brackets are the monocrop weed biomass for the monocrop treatments, and the standard errors of mean for the intercrop treatments.

Table 4-7. Ability to compete (AC) and ability to withstand competition (AWC) least-square means for the cropping treatments at the Edmonton organic location in 2006 and 2007 (n=8).[z]

Cropping treatments	AC	AWC
	(%)	
Wheat (W)	74	67
Barley (B)	97	76
Canola (C)	24	32
Pea (P)	31	46
Wheat-Barley (WB)	90	68
Wheat-Canola (WC)	72	56
Wheat-Pea (WP)	62	53
Wheat-Barley-Canola (WBC)	88	79
Wheat-Barley-Pea (WBP)	88	61
Wheat-Canola-Pea (WCP)	63	57
Wheat-Barley-Canola-Pea (WBCP)	85	64
F $test_{intercrop}$	***	*
SE of diff $_{intercrop}$ [y]	9.1	12.1

[z]ns= not significant (P≥0.10), * significant at P<0.10, ** significant at P<0.05, *** significant at P<0.01.
[y] Standard error of the difference of two lsmeans.

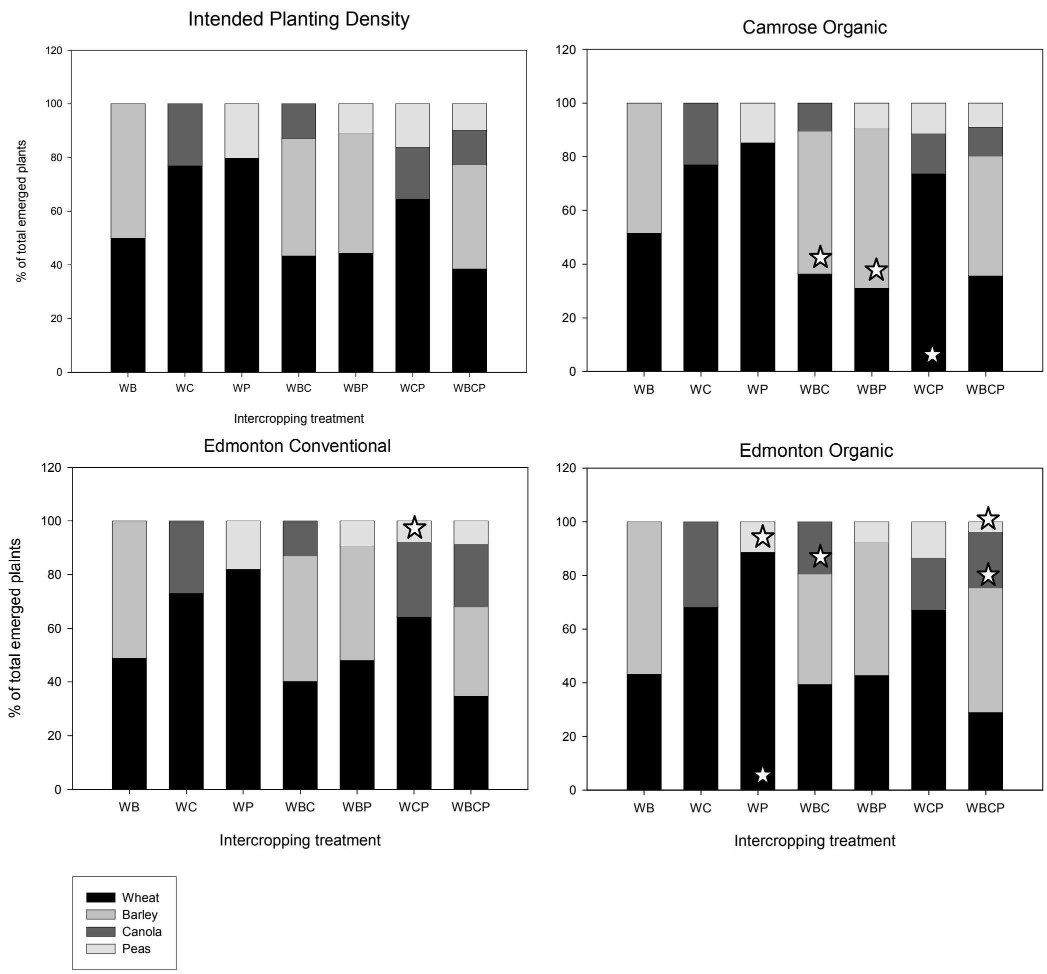


Figure 4-1. Percent of intended planting density in intercropping treatments, and actual emerged plant ratios (reported as percent of total emerged plants) by crop species for the intercropping treatments grown at the Camrose and Edmonton locations in 2006 and 2007 under organic and conventional management. Crops that had significantly different (P<0.05) percent emerged seedlings versus the seeding ratios are indicated with a star. Crops present in intercrops indicated by letters (W = Wheat, B = Barley, C = Canola, P = Pea).

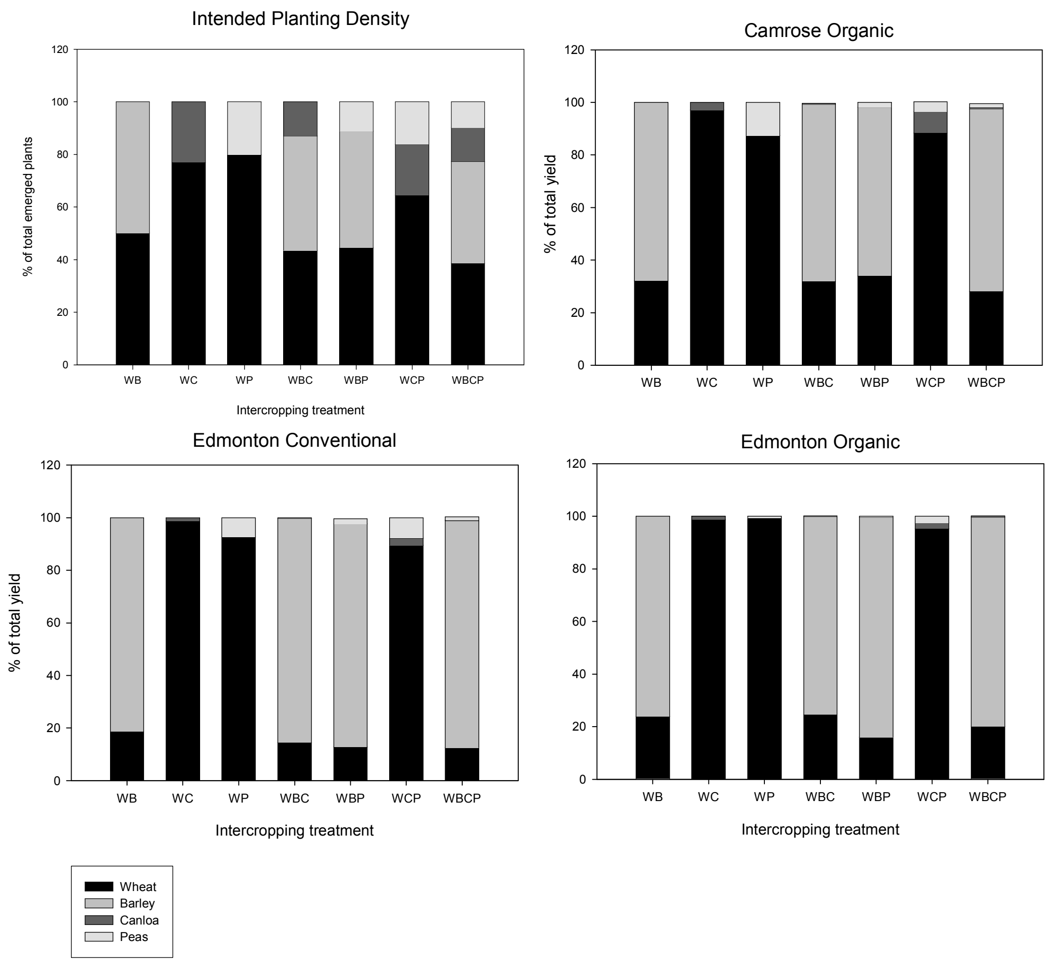
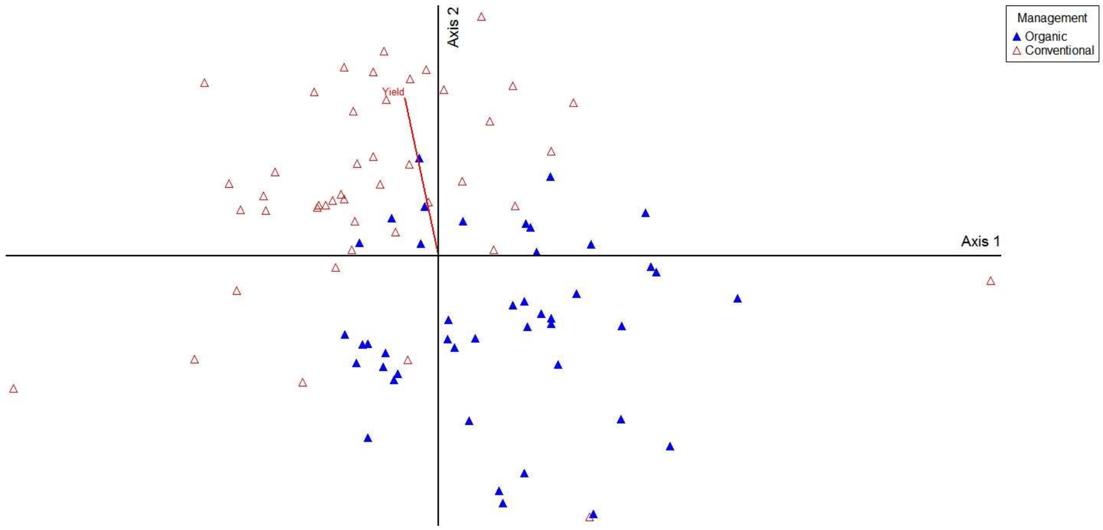
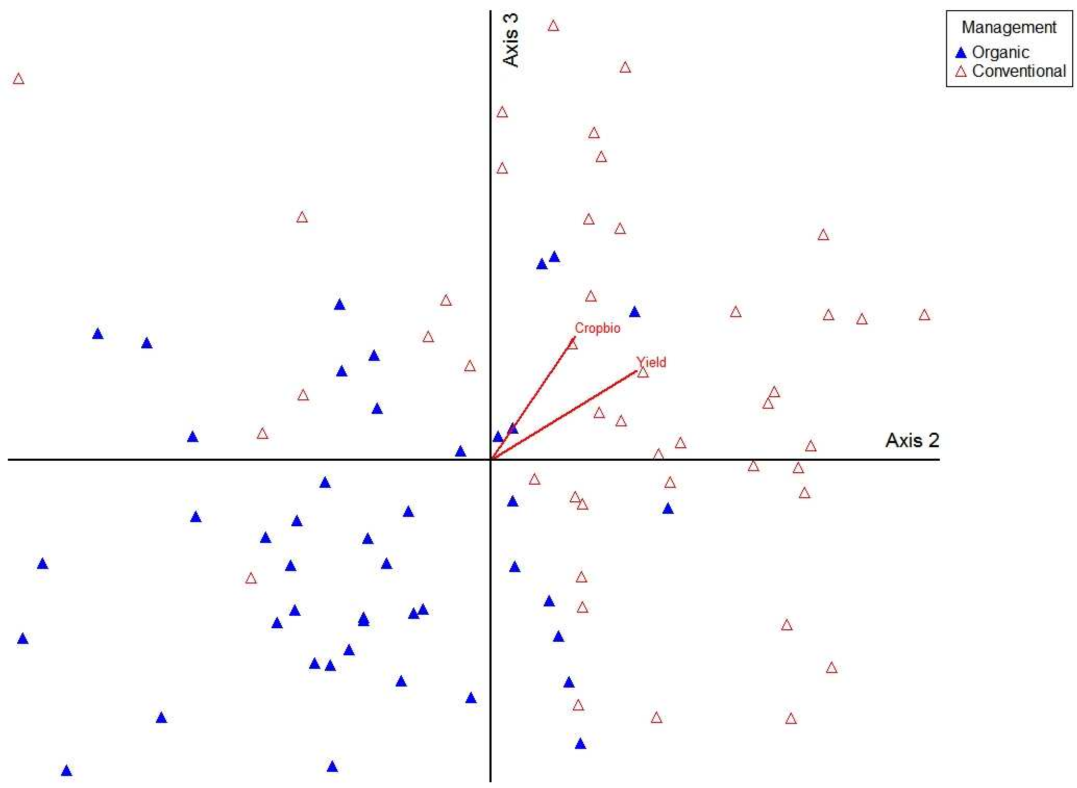


Figure 4-2. Intended planting density and percent of total grain yield (by weight) by crop species for the intercropping treatments grown at the Camrose organic, Edmonton organic and Edmonton conventional locations in 2006 and 2007. Crops present in intercrops indicated by letters (W = Wheat, B = Barley, C = Canola, P = Pea).



(a)



(b)

Figure 4-3. NMS ordination of soil PLFA profiles from 2006 and 2007 experimental sites in Edmonton, Alberta, grouped according to organic and conventional management systems. Figure (a) shows axis 1 and 2, (b) shows axis 3 and 2 of the three dimensional ordination solution.

Table 4-8. Multi-response permutation procedure results for microbial community structure for mono- and intercrops of annual crops grown organically and conventionally in Edmonton, AB in 2006 and 2007.

Comparison		T	A	*p*
Edmonton				
Management	Conventional vs. Organic	-27.48	0.106	$<0.0\times10^{-7}$
Year	2006 vs. 2007	-10.27	0.039	0.65×10^{-6}
Cropping treatment	All	0.291	-0.004	0.592
Management×Mix	All	-5.06	0.102	0.57×10^{-5}

Table 4-9. Phospholipid fatty acid analysis (PLFA) indicator species associated with soils under different mono- and intercropping treatments grown organically or conventionally at Edmonton, AB in 2006 and 2007.

PLFA	Origin		Indicator value		Monte Carlo
		Mean	Conv.	Organic	p<0.05
10Me16:0	Actinomycetes	50.2 (0.73)	49	51	0.0002
a17:0	Gram +	50.2 (0.72)	49	51	0.0002
cyc17:0	Bacteria	50.3 (0.74)	51	49	0.0002
16:1 2OH	Bacteria	50.4 (0.79)	47	53	0.0002
18:3ω6,9,12c	Fungi	38.0 (3.33)	63	14	0.0002
i18:0	Gram +	13.3 (3.04)	31	0	0.0006
18:1ω9c	Gram -	50.2 (0.73)	51	49	0.0002
18:1ω5c	Gram -	33.8 (3.63)	7	67	0.0002
18:2ω6,9c / a18:0	Fungi/Gram +	50.9 (0.98)	57	43	0.0002

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5.0 General Discussion and Conclusions

5.1 Introduction

Agricultural systems develop in stages by solving three challenges: the first challenge is to increase yields, the second challenge is to improve production efficiency, and third is to improve the safety, quality and environmental sustainability of the food system (Schneeman 2000). Canadian agriculture has achieved high yields and has continually increased production efficiencies. It is now time to strive for increased nutritional value of crops and environmental sustainability of the food system. Consumers are becoming increasingly concerned with food safety, the presence of pesticides and genetically modified organisms in their grain products, and the negative environmental effects of conventional agriculture (Klonsky 2000). Improvements in nutritional quality of grains must come from environmentally sustainable practices, such as designing cropping systems to enhance nutrient uptake through mycorrhizal function and soil microbial diversity.

Production constraints are similar in organic and conventional systems, however, in the absence of inorganic fertilizers and pesticides, organic systems tend to have higher weed pressure and lower soil nutrient levels than their conventional counterparts (Entz et al. 2001; Snyder and Spaner 2010). To deal with these constraints, farmers can adopt various cropping practices, including intercropping and cultivar selection.

One requirement of a well-functioning soil is 'diversified and abundant populations of soil organisms to mobilize nutrients' (Uphoff et al. 2006). Farmers can influence the structure of soil microbial communities through cropping practices such as crop rotations, crop choice, tillage, and inputs (Brussaard et al. 2007). However, cropping practices have aspects of site-specificity in their effect on microbial communities, making broad generalizations about the effect of a particular practice on microbial structure difficult, and little work has been done in central Alberta on the impact of specific practices on crop quality and soil microbial structure, especially in organic systems.

The specific objectives were to 1) determine the effect of organic and conventional management and spring wheat cultivar choice on soil microbial communities, crop productivity, and breadmaking quality in central Alberta; 2) compare the concentrations of seven minerals, including Se, Cu, Mn, Zn, Fe, Mg and K in a subset of hard spring wheat cultivars grown over the last 100 years in western Canada in both conventional and organic environments; 3) explore the effect of the microbial community structure in organic and conventional management systems on micronutrient content; 4) compare monocultures of spring wheat, barley, canola and peas, along with all 2-, 3- and 4-crop intercrop combinations with wheat for productivity and weed suppression under both organic and conventional management systems; and 5) determine effect of intercrops of common annual crops grown on the Canadian prairies on soil microbial communities under organic and conventional management systems.

5.2 Spring wheat genotypes differentially alter soil microbial communities and wheat breadmaking quality in organic and conventional systems

Five western Canadian spring wheat cultivars representing commonly grown cultivars from the past century were grown on one organically managed site and one conventionally managed site in 2005, 2006 and 2007 in Edmonton, AB (Chapter 2.0).

Organic grain yields were roughly half of conventional yields, which is indicative of the trend to lower yields in organic systems (Entz et al. 2001). The yield loss in the organic system is partly attributable to crop competition with weeds (Mason et al. 2007), as well as delayed seeding, which has been reported to lower grain yields (Hunt et al. 1996).

Although most of the quality traits varied between the organic and conventional grain, both systems had acceptable quality levels. Grain protein levels were higher in the organic system than in the conventional system; however, protein levels were high for all cultivars at both the organic and conventional sites, with values above the minimum standard for CWRS wheat of 13.5%. Flour yield and particle size index were lower in the organic system, while peak height and total energy under the graph were higher in the organic system. This study suggests that organic grain quality equal to or better than conventional systems is possible to achieve.

The organic system had higher % Gram negative and Gram positive bacteria and % mycorrhizal fungi than the conventional system. Richness and diversity was also greater in the organic system than the conventional system. Measured soil microbial profiles differed between the two management systems. Weeds were more prevalent in the organic system, and we believe their presence contributed to the microbial differences present between the two management systems. There were some moderate positive correlations between microbial diversity and breadmaking quality parameters in the conventional system. In the organic system, the proportion of mycorrhiza fungi in the soil had a strong positive correlation with yield, indicating that mycorrhizal fungi had a positive role in productivity of wheat plants in the organic system but no effect in the conventional system.

The influence of cultivar on the soil microbial community structure was only detected in the relatively weed-free conventional system. In the conventional system, the most recent (and highest yielding) cultivar, AC Superb, exhibited the highest levels of all PLFA traits; most notably % fungi. Some studies suggest that mycorrhizal dependency is being bred out of modern wheat cultivars (Hetrick et al. 1993; Zhu et al. 2001). Our results suggest that breeding efforts in conventionally managed environments may have resulted in cultivating mycorrhizal dependence in that environment.

5.3 The soil microbial community and grain micronutrient concentration of historical and modern hard red spring wheat cultivars grown organically and conventionally in the black soil zone of the Canadian Prairies

Using the same experimental design as in Chapter 2.0, five spring wheat cultivars were grown under organic and conventional management regimes in Edmonton, AB (Chapter 3.0).

The organic system in the present study had higher grain Zn, Fe, Mg and K, but lower grain Se and Cu. In general, then, many of the studied micronutrients were greater in the organic system. However, only one of the three antioxidants studied (Zn, Se and Cu) was indeed present in the grain in greater concentrations in the organic system studied here. Decreased grain yield, and possibly smaller grain size, may, in part, account for increased grain nutrient concentration in the present organic system. However, the use of composted manure in the organic system did appear to supply nutrients for improved levels of grain nutrient concentrations. Future studies are needed to determine the impact of other agronomic cropping practices and to identify best management practices within organic and conventional systems for soil fertility and final crop quality.

Significant interaction effects of management × cultivar indicate that the choice of wheat cultivar to maximize grain micronutrient level is dependent on management system. Glenlea grown organically had the highest grain nutrient levels compared to cultivars grown either organically and conventionally. Our results suggest that breeding for elevated grain quality and yield in western Canadian hard red spring class has resulted in the retention of micronutrient quality characters.

Organic and conventional management systems have different soil microbial communities. The organic system had higher levels of fungi in the soil, including AM fungi, and these fungi biomarkers appears to have improved the uptake of Mn and Cu**.**

Our results suggest that nutritional advances in the micronutrient content of wheat can be made through the choice of management system and through plant breeding. Such advances do not necessarily have to come at the expense of elevated or stable grain yield.

5.4 Annual grain-broadleaf intercrops increase weed competitive ability in organically managed systems in the northern Great Plains

A field experiment was conducted in 2006 and 2007 at paired organically and conventionally managed sites in Edmonton, Alberta and on a certified organic farm near Camrose, Alberta to compare annual crop monocultures and mixtures (Chapter 4.0).

Land equivalent ratios for grain yield greater than one were achieved for wheat-barley-pea and wheat-barley-canola-pea mixtures in organically managed systems in this study. Intercropping benefits in this study were largely attributed to the ability of the intercrops to suppress weeds, as weed pressure was high at the two organic locations. This experiment demonstrates that intercropping a competitive crop, such as a cereal like wheat or barley, with a less competitive crop, such as peas or canola, can result in intermediate weed suppression levels between the component crops. The use of an extremely competitive cultivar such as Seebe barley resulted in a dominance of this crop in the final yield and, in part, negated the economic benefit of the intercrop. However, intercrops also showed an ability to overyield in a conventional system where weeds are controlled through herbicides.

The most complex intercropping treatment, wheat-barley-canola-pea, had weed suppression above that of component crops at both organic sites and at the conventional site, as measured by mean relative weed biomass. The three- and two-crop intercropping treatments also exhibited weed suppression above the component crops, in fewer instances and with decreasing intercrop complexity.

Management system and year affected the composition of the soil microbial community, but phospholipid fatty acid diversity indices were largely not affected by cropping treatment, with the exception of PLFA evenness under conventional management at the Edmonton location. We expected the intercrops, with a greater diversity of plants and sources of organic matter, would have a greater diversity of soil microbes. With annual intercrops grown for one year at a site, there may not have been sufficient time for the intercrops to affect the soil microbial community.

5.5 General Discussion

Consumers purchase organic food products because they believe these products to have superior quality attributes to comparable conventional products. To ensure that organic systems are producing the highest quality crop possible we must develop an understanding of the impact of cropping practices on final crop quality, particularly in organic systems, where research is limited. As well, we must work to continually improve the environmental sustainability of our cropping systems.

Organic wheat grain quality equal to or better than conventional grain quality is possible to achieve. Research in this thesis supports the findings that there is a tendency for weed pressure to be higher and grain yields lower in organic systems. Cultivar choice did have an effect on yield, grain quality and soil microbial communities, and was often management system specific. The modern cultivars, such as AC Superb, yielded the highest in both systems, and also showed the highest level of mycorrhizal fungi markers in the conventional system. This indicates that mycorrhizal dependency has not been bred out of modern wheat cultivars in conventional environments. As well, breeding for increased grain yield has not resulted in a loss of micronutrient content of wheat.

The soil microbial communities differed between the organic and conventional cropping systems. This indicates that the cropping practice differences translate into different soil microbial community structure and possibly different soil fertility systems. Differences in the soil microbial community structure, and possibly in the function will most likely lead to differences in best management practices for final crop quality.

Annual intercropping where the crops are grown for grain yield presents a possible crop management strategy for both organic and conventional farmers. Intercrops have the potential to reduce dependence on inorganic pesticides and fertilizers in conventional systems, and reduce tillage intensities and improve soil fertility status in organic systems. Results from the thesis research indicated that intercrops can increase crop productivity over their component monocrops. Including a competitive crop, such as barley, in the intercrop improved the weed suppression of the intercrop. Increasing complexity of the intercrops (adding more crops into the mixture) resulted in more consistent weed suppression over sites and treatments.

5.6 Recommendations for Future Research

The studies in this thesis research used phospholipid fatty acids as a measure of soil microbial community, and interpreted the results of the microbial community using established biomarkers. Functional structure of the microbial community must be studied to begin to interpret how differences in organic and conventional soil systems may lead to differences in crop quality. This research focused on the microbial community as a whole, however, arbuscular mycorrhizal fungi (AMF) play an important role in nutrient uptake in plants. Future studies should measure AMF directly by collecting root samples and measuring plant colonization by fungi. As well, we believe the presence of weeds had a large influence on the soil microbial community as well as crop productivity. Controlled field experiments with and without the presence of weeds would help to tease out the role of weeds in organic systems on the soil microbial community. Future studies are needed to determine the impact of other agronomic cropping practices and to identify best management practices within organic and conventional systems for soil fertility and final crop quality. A limited number of cultivars were chosen to represent a broad range of cultivars and traits. To draw conclusions regarding the traits that may affect soil microbial communities, a larger sample of wheat cultivars should be studied. The benefits of mycorrhizal fungi have been associated with increased phosphorus uptake. Studies that examine the mycorrhizal colonization of cultivars and the effect of colonization levels on phosphorus uptake are needed to determine the potential benefits of mycorrhiza in Canadian organic systems.

Annual intercropping has potential environmental, agronomic and economic benefits in both organic and conventional cropping systems. However, to maximize the benefits of these systems (economic performance, weed suppression, etc.), further research is required to establish recommendations on seeding rates, relative plant densities, planting schemes and cultivar choice of component crops. Studies that include the economic performance of the systems will help farmers decide if they are interested in intercropping. Research including the effects of intercropping systems on the Kingdom Animalia are also needed. Research on harvest technologies must be done prior to wide-scale adoption of intercropping systems to ensure that crops can be separated at harvest.

5.7 Original Contributions to Knowledge

Our understanding of soil microbial communities in agricultural systems, and the impact of cropping practices on these communities are poorly understood. Research on soil microbial communities in organic systems in Canada is limited, and often focuses on one organism, rather than the whole community.

The impact of cropping systems on soil microbial communities is complex, involving many factors including: soil type, climate and cropping system practices. Chapter 1.0 is a review of the literature on the impacts of cropping management practices on soil microbial diversity and arbuscular mycorrhizal communities. It is, to the best of my knowledge, the first review to focus on common crop management practices used in Canadian organic and conventional systems, and summarize their impacts on soil microbial communities.

The experiment in Chapters 2.0 and 3.0 examined five spring wheat cultivars grown in organic and conventional management systems. The effect of wheat cultivars on rhizosphere soil microbial communities has been studied to some degree (Germida and Siciliano 2001; Siciliano et al. 1998), but not under organic conditions in Canada, to my knowledge. As well, connections between the structure of the soil microbial community and final grain breadmaking quality and nutrient content have not been made in Canadian organic systems. With speculation on the suitability of modern, high-yielding cultivars for organic production, these studies suggested that cultivars have not lost mycorrhizal dependency or micronutrient content through breeding efforts. These studies also demonstrated that organic grain quality equal to, or better than, conventional systems is possible to achieve. The results provide evidence that breeding efforts of the western Canadian hard red spring class has resulted in the retention of micronutrient quality characters.

Chapter 4.0 investigated annual crop monocultures and mixtures under organic management. Intercropping research where all component crops are considered main crop species and harvested for grain is limited in the Canadian prairies. As well, little research has been carried out on complex (three- or four-crop) annual intercropping systems in the Canadian prairies. No such studies exist in organic systems in western Canada. This experiment suggested that crop productivity can be increased with annual intercrops in organic systems. The study demonstrated that the addition of a competitive crop in an intercrop can improve weed suppression, and suggested that increasing the complexity of the intercrop increased the weed suppression. The study identified no differences in soil microbial community structure due to intercropping over one field season.

This thesis constitutes an 'advancement of knowledge in the domains in which the research was conducted'. The impacts of cropping practices on soil microbial communities were reviewed, and effects of cultivar selection and intercropping on organic crop productivity and microbial communities in the northern Canadian Prairies were established. Differences in cultivar quality under organic and conventional management systems were identified. Organic systems can produce grain quality equal to, or better than, conventional systems. The choice of cultivar is an important determinant of grain quality, and is dependent on management system. Management systems and wheat cultivars can affect the composition of the soil microbial community. Intercrops did not affect soil microbial community in this study, but they did show agronomic benefits through improved weed suppression and crop productivity.

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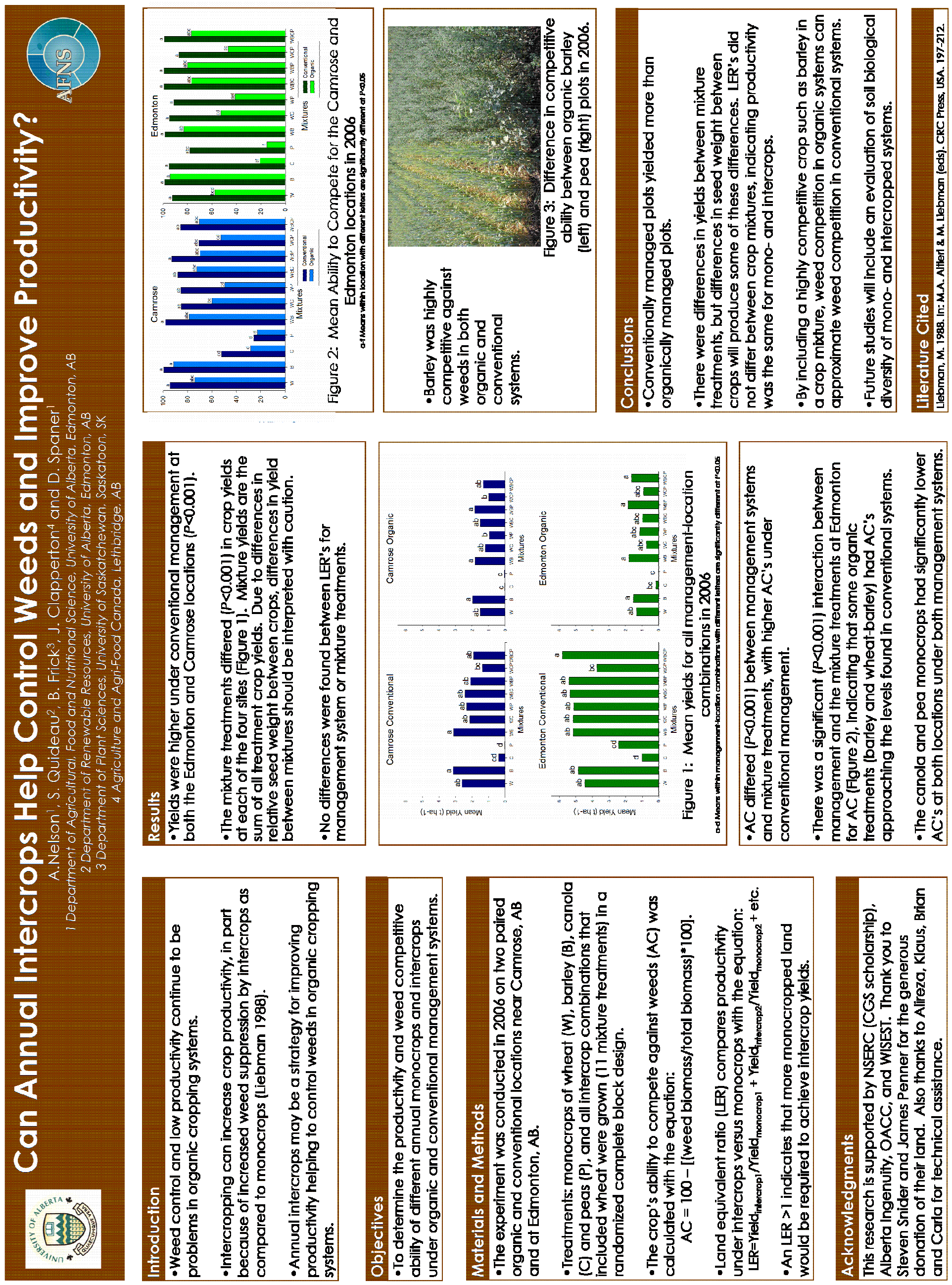
6.0 Appendices

Appendix 6-1. Poster presented at Organic Connections Conference in Saskatoon, SK, November 12-14 (second place winner in graduate student competition)



Appendix 6-2. Poster presented at International Federation of Organic Movements Organic World Congress in Modena, Italy, June 16-20, 2008; and at the Organic Connections Conference in Saskatoon, SK, November 16-18, 2008 (second place winner in graduate student competition).

Does Wheat Cultivar Choice Affect Crop Quality and Soil Microbial Communities in Cropping Systems?

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Introduction

- Research into nutritional and sensory differences of organic and conventional products has not yielded consistent results (Bourn and Prescott 2002).
- Soil microbes play an important role in nutrient cycling and are affected by production practices.
- Cropping systems management (organic and conventional) (Bossio et al. 1998) and cultivar selection (Germida and Siciliano 2001) may alter microbial communities.
- Understanding how cultivar choice affects microbial communities and crop quality may result in production systems with consistently high food quality.

Objectives

- To determine the effect of spring wheat (*Triticum aestivum* L.) cultivar choice on soil microbial communities, crop productivity and breadmaking quality in organic and conventional systems.

Materials and Methods

- The experiment was grown in 2005 and 2006 in Edmonton, AB on 2 sites: 1 organically managed and 1 conventionally managed.
- 6 western Canadian spring wheat cultivars were grown in a randomized complete block design: Elsa, Glenlea, Go, Marquis, Park and Superb.
- Breadmaking quality measures were taken on the harvested grain (Table 1).
- Phospholipid fatty acid analysis (PLFA) was used to measure the soil microbial community (Table 1).

Table 1: Breadmaking quality and phospholipid fatty acid analysis (PLFA) measures taken from harvested grain and soil samples, respectively, from a field study in Edmonton, AB in 2005 and 2006.

Breadmaking quality measures	PLFA measures
Yield	Total biomass
Grain protein	% Gram- bacteria
Flour yield (FLY)	% Gram+ bacteria
Falling number (FN)	% Fungi
Particle size index (PSI)	PLFA richness
Mixing development time (MDT)	PLFA evenness
	PLFA diversity

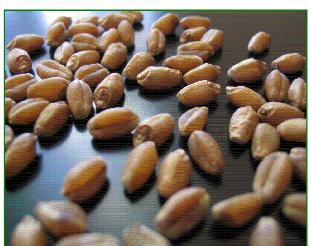

Figure 1: Harvested grain was analyzed for a number of processing quality traits.

Figure 2: Organic plots, showing height differences between two cultivars.

Results

- Wheat cultivars differed for all breadmaking quality measures, except yield in the organic system (Table 2).
- Although cultivars differed for quality measures, most fell within accepted standards.

Table 2: Results of statistical analysis on selected breadmaking quality parameters for wheat grown organically and conventionally in Edmonton, AB. The two management systems were analyzed separately.

Cultivar	Yield ($t\ ha^{-1}$)	Grain protein (%)	FN	MDT (min.)
		Organic		
Elsa	2.2	16.3	581	2.2
Glenlea	2.1	17.0	410	3.4
Go	2.6	16.0	265	2.9
Marquis	2.0	15.4	510	2.1
Park	2.2	16.2	492	2.3
Superb	2.4	15.6	426	1.9
Mean	2.1	16.9	472	2.4
$F\ test_{cultivar}$	ns	***	***	***
$SE_{cultivar}$	0.77	0.46	78	0.16
		Conventional		
Elsa	5.6	15.9	540	2.1
Glenlea	6.0	14.6	369	4.6
Go	5.6	15.3	457	3.0
Marquis	4.5	15.7	494	1.7
Park	5.1	15.2	547	2.2
Superb	6.2	14.6	502	2.2
Mean	5.3	15.1	486	2.7
$F\ test_{cultivar}$	***	***	***	***
$SE_{cultivar}$	0.49	0.2	22	0.26

ns= not significant (P=0.10), *** significant at P<0.01, FN=falling number, MDT=mixing development time, SE=standard error

- Management had a significant effect (P<0.10) on yield and grain protein levels (data not shown).
- Organic yields were about ½ of conventional yields.
- Grain protein levels were 12% higher in the organic system.
- Cultivar had no effect on the soil microbial community in the organic system.
- There were more significant correlations between grain quality and the soil microbial community in the organic system (Table 3).
- The % Fungi was positively correlated with yield in both systems.

Table 4. Selected Pearson correlation coefficients between lsmeans of wheat grain breadmaking measures and soil microbial measures from the organic field sites in Edmonton, AB in 2005 and 2006

	Yield	PRO	PSI	FN	FLY	MDT
% Gram- bacteria	-0.68**	-	-	-	-	-
% Gram+ bacteria	-0.60*	0.58*	-0.62**	-	-	0.67**
% Fungi	0.91**	-	0.70**	0.66**	-	-
PLFA Richness	-0.91**	-	-	-	-0.58*	-
PLFA Evenness	-0.79**	0.56*	-0.58*	-	-	-
PLFA Diversity	-0.91**	0.57*	-0.59*	-	-	-

*, ** denotes r values significant at P<0.10, P<0.05, respectively. - denotes no significant correlation (P>0.10), PRO=grain protein, PSI=particle size index, FN=falling number, FLY=flour yield, MDT=mixing development time

Conclusions

- Yields were lower in the organic system, but protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems.
- Cultivar choice altered grain quality and yield in both systems, but did not have an effect on soil microbial communities in the organic system.
- More significant correlations in the organic system may indicate that soil microbes play a greater role in determining crop quality in organic systems than in conventional systems.

Figure 3: Wheat in field plots.

Acknowlegements

Thanks to the Natural Sciences and Engineering Research Council, Alberta Ingenuity and Alberta Crop Industry Development Fund for financial support.

Thanks to Klaus Strenzke, Alireza Navabi and David Niziol for technical and scientific support.

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Appendix 6-3. Paper from poster presentation given at Organic World Congress, Modena, Italy, June 16-20, 2008.

[Nelson, A., Frick, B., Clapperton, J., Quideau, S. and Spaner, D. 2008. Does wheat cultivar choice affect crop quality and soil microbial communities in cropping systems? Proceedings, 16th IFOAM Organic World Congress, Modena, June 16-20, 2008. Archived at **http://orgprints.org/12070** - peer-reviewed]

Does Wheat Cultivar Choice Affect Crop Quality and Soil Microbial Communities in Cropping Systems?

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Key words: wheat, soil microbial community, breadmaking quality, organic and conventional management

Abstract

Wheat (Triticum aestivum L.) *cultivars may have differential effects on soil microbial communities and the breadmaking quality of harvested grain. We compared six Canadian spring wheat cultivars under organic and conventional management systems for yield, breadmaking quality and soil phospholipid fatty acid analysis (PLFA) profile. Yields were lower, but protein levels were higher in the organic system. Cultivars differed for quality traits, but all cultivars had acceptable levels for processing. There were small differences in PLFA profiles for cultivars in the conventional system, but none in the organic system. More significant correlations between grain quality and PLFA measures were present in the organic system. Protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems. Wheat cultivars differed for grain quality in both organic and conventional systems, and cultivars altered the soil microbial profile in conventional systems. Microbes may play a greater role in determining crop quality in organic systems than in conventional systems.*

Introduction

Demand for organic foods has been increasing in Canada, in part because consumers perceive organic foods as having unique and/or superior quality than conventionally produced foods (Yiridoe et al. 2005). Research into the nutritional differences and sensory profiles of organic and conventional products has not yielded consistent results (Bourn and Prescott 2002).

Soil microbial communities play an important role in soil fertility and nutrient cycling, and are affected by production practices. Cropping systems management (organic and conventional) may (Bossio et al. 1998) or may not (Girvan et al. 2003) alter soil microbial communities. Crop cultivar selection can also affect soil microbial diversity (Germida and Siciliano 2001).

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Understanding the effects of cultivar choice on soil microbial communities and crop quality may result in production systems with consistently high food quality. Our objectives were to determine the effect of spring wheat (*Triticum aestivum* L.) cultivar choice on soil microbial communities, crop productivity and breadmaking quality in both organic and conventional systems.

Materials and methods

Six western Canadian spring wheat cultivars (Elsa, Glenlea, Go, Marquis, Park and Superb) were grown in four-replicate randomized complete blocks on two nearby sites (one organically managed and one conventionally managed) in 2005 and 2006 in Edmonton, AB, Canada (55°34´N, 113°31´W). The two sites had similar soil types.

Quality measures on grain included a number of processing measures which relate to final product quality. Protein levels over 12% are considered adequate in western Canada. Flour yield (FLY) is a measure of milling quality. Falling number (FN) indicates the sprouting resistance of the grain, affecting dough quality; grain over 400 has high sprouting resistance. Particle size index (PSI) indicates kernel hardness, with values generally 50-55 PSI. Mixing development time (MDT) is a measure of how long it takes to develop the dough; values between 2-3 minutes are desired. Soil biological biomass, % Gram- and Gram+ bacteria, % fungi, richness, evenness and diversity was determined using phospholipid fatty acid analysis (PLFA) on 5 soil samples randomly removed from each plot during crop growth (Clapperton et al. 1997).

Proc Mixed in SAS v.9.0 was used to analyze the combined experiment as a split plot, with management system as the main plot and cultivar as the subplot, replicated in time (year). The data were also analyzed separately by management system combined over years. For both analyses, years and blocks were considered random and management system and cultivar were considered fixed effects. Pearson correlations were conducted on site-year lsmeans.

Results

Table 1: Results of combined and separate statistical tests of breadmaking quality traits of wheat cultivars grown organically and conventionally

Cultivar	Yield ($t\ ha^{-1}$)	Grain protein (%)	FLY (%)	FN	PSI (%)	MDT (min.)
	Conventional					
Conventional mean	5.3	15.1	73	486	52	2.7
F test $_{cultivar}$ (df=5)	***	***	***	***	***	***
SE $_{cultivar}$	0.49	0.20	1	22	1	0.26
	Organic					
Organic mean	2.1	16.9	70	472	49	2.4
F test $_{cultivar}$ (df=5)	ns	***	***	***	***	***
SE $_{cultivar}$	0.77	0.46	1	78	2	0.16
	Combined ANOVA					
F test $_{mgmt}$ (df=1)	*	*	NS	NS	NS	NS
SE $_{mgmt}$	0.53	1.01	1	32	1	0.16
F test $_{cultivar}$ (df=5)	**	NS	NS	*	***	***
SE $_{cultivar}$	0.52	0.94	1	43	1	0.21
F test $_{mgmt*cultivar}$ (df=5)	*	NS	NS	NS	*	NS

NS=not significant (P≥0.10), * significant at P<0.10, *** significant at P<0.01, FLY=Flour yield , FN=Falling number, PSI=Particle size index, MDT=Mixing development time, SE=Standard error

When the management systems were analyzed separately, cultivars differed (P<0.01) for all breadmaking quality measures, except yield in the organic system (Table 1). Although cultivars differed for quality measures, most exhibited quality measures falling within accepted standards. However, Glenlea in the conventional system, and Go in the organic system had falling numbers below 400, suggesting these cultivars may have inferior dough under certain management systems.

In combined analyses, management had a significant effect on yield and grain protein. Yields under organic management were about half of those under conventional management. Grain protein levels were 12% higher in the organic system compared to the conventional system. Cultivar was a significant source of variation for all breadmaking quality traits except protein and FLY, with most values within standards.

The interaction of management × cultivar was significant (P<0.10) for yield and PSI. Superb yielded more grain than Marquis in the conventional system. Marquis yielded the lowest of the six varieties in both systems.

In the separate analysis for the PLFA measures, cultivar altered (P<0.05) % fungi, PLFA evenness and diversity in the conventional system (Table 2). Superb had higher % fungi, PLFA evenness and diversity than the other cultivars. Cultivar did not alter (P>0.10) any of the PLFA measures in the organic system.

Table 2: Lsmeans of cultivars under conventional management for % fungi, PLFA evenness and diversity from management-separated statistical tests

Cultivar	% Fungi	Evenness	Diversity
Elsa	0.93 b	0.82 ab	2.63 ab
Glenlea	0.90 b	0.80 b	2.61 b
Go	1.02 ab	0.82 ab	2.68 ab
Marquis	0.91 b	0.82 ab	2.68 ab
Park	1.05 ab	0.79 b	2.57 b
Superb	1.37 a	0.85 a	2.81 a

Lsmeans followed by the same letter within columns are not significantly different at the P<0.05 level, with Tukey's adjustment. Lsmeans separation was carried out using the pdiff option in SAS.

Correlation analysis suggested some relationships between grain quality and the soil microbial community in both systems, with more correlations in the organic system. Eighteen of 42 correlations were significant in the organic system, and only seven of 42 correlations were significant in the conventional system (data not shown). The % fungi was positively associated with yield under organic management (r=0.9***) and under conventional management (r=0.7**).

Discussion

Protein content of grain is an important factor in breadmaking quality, and was higher in the organic system. Other experiments have reported protein levels in organic systems to be lower (Poutala et al. 1993) or the same (Ryan et al. 2004) as conventional systems. Lower yields and heavy applications of compost for many years prior to the wheat crops in the organic system may explain the higher protein content in organic wheat. However, this experiment demonstrates that it is possible to have similar protein levels in organic and conventional systems.

Cultivars chosen for this experiment differed for some measures of quality as well as yield in both organic and conventional systems. The oldest cultivar, Marquis, yielded lowest in both the organic and conventional system, indicating that breeding has improved yields over the last century. Cultivar choice also affected some measures of the soil microbial community, but only in the conventional system. Management system did not affect microbes. It appears that factors other than cultivar are important in determining microbial community structure in organic systems.

More significant relationships between grain quality and soil microbes in the organic system may indicate that soil microbes play a greater role in determining crop quality in the organic system than the conventional system. The positive correlation between yield and % fungi may be due in part to mycorrhizal fungi (Olsson et al. 1999), as mycorrhizae can benefit plant nutrient uptake and crop productivity.

Conclusion

Yields were lower in the organic system, but protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems. Cultivar choice altered grain quality and yield in both systems, but did not have an effect on soil microbial communities in the organic system. Soil microbes may play a greater role in determining crop quality in organic systems than in conventional systems.

Acknowledgments

We gratefully acknowledge the financial support of the Natural Sciences and Engineering Research Council, Alberta Ingenuity and a research grant from the Alberta Crop Industry Development Fund. Thanks to K. Strenzke and A. Navabi for technical and scientific support.

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Appendix 6-4. Paper from oral presentation given at: International Conference on Organic Agriculture in Scope of Environmental Problems, Famagusta, Cyprus, February 3-7, 2010.

ARE SOME WHEAT CULTIVARS BETTER SUITED TO ACHIEVE HIGH QUALITY IN ORGANIC SYSTEMS?

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Abstract
Consumers purchase organic food because these products are perceived to have superior quality attributes over conventional foods. A field study compared five Canadian spring wheat cultivars grown organically and conventionally for yield, breadmaking quality and nutrient content. Results suggest protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems. Composted manure appeared to supply micronutrients to the organic system for improved levels of grain nutrient content. Cultivar choice is important in determining grain quality, especially nutrient content in organic systems.

Keywords
Spring wheat, breadmaking quality, grain nutrient content, fertility amendments

Introduction
Some consumers purchase organic food because they perceive the products to have superior quality attributes over conventional foods [1]. Despite perceived benefits of consuming organic foods, organic certification is based on the process used to produce the good, not on the product itself. This suggests that organic products may not be superior to conventional ones [2]. Research into nutritional differences of organic and conventional products has not yielded consistent results [3].

Soil, climate, crop type and cultivar, management practices and post-harvest factors can all affect the nutritional quality of crops [4]. Our objectives were to determine the effect of spring wheat (*Triticum aestivum* L.) cultivar choice on yield, breadmaking quality and grain nutrient content in organic and conventional cropping systems in order to design systems that produce consistently high food quality.

Materials and Methods
We conducted a field study 2005-2007 to compare five western Canadian spring wheat cultivars (AC Elsa, Glenlea, Marquis, Park and AC Superb) grown under organic and conventional management systems for yield and grain quality. The study was located in Edmonton, AB, Canada (55°34´N, 113°31´W), on two nearby sites with similar soil types. Yield, grain protein levels, flour yield and grain Cu, Mn, Zn, Fe, Mg and K concentrations were determined on harvested grain.

Proc Mixed in SAS v.9.0 was used to analyze the combined experiment as a split plot, with management system as the main plot and cultivar as the subplot, replicated in time (year). The data were also analyzed separately by management system combined over years. For both analyses, years and blocks were considered random and management system and cultivar were considered fixed effects.

Results

Table 1: Yield, Breadmaking Quality and Grain Nutrient Content for Wheat Grown Organically and Conventionally in Edmonton, AB in 2005, 2006 and 2007

Cultivar	Yield	Grain protein	Flour yield	Cu	Mn	Zn	Fe	Mg	K
	($t\ ha^{-1}$)	*(%)*	*(%)*	*(ppm)*	*(ppm)*	*(ppm)*	*(ppm)*	*(ppm)*	*(ppm)*
Organic									
AC Elsa	2.80	16.8	72	2.83	29	49.1	57.3	1278	3296
Glenlea	2.78	17.2	69	4.02	35.4	56	63.5	1390	3443
Marquis	2.38	16.0	69	2.83	29.4	49.2	56.5	1352	3110
Park	2.65	16.7	71	2.75	29.4	48	53.8	1375	2989
AC Superb	3.11	16.3	70	3.02	33.7	46.6	61.3	1376	3259
F $test_{cultivar}$	***	***	***	***	***	*	***	**	***
$SE_{cultivar}$	0.796	0.350	1	0.469	4.98	6.73	5.02	62.2	173.6
Conventional									
AC Elsa	5.09	16.0	74	4.99	31.1	44.2	50.72	1285	2995
Glenlea	5.57	14.5	73	4.02	31.3	39.9	47.42	1171	3101
Marquis	4.04	15.6	71	4.00	32.6	46.3	47.48	1299	2886
Park	4.66	15.3	72	4.50	31.9	44	43.39	1306	2770
AC Superb	5.73	15.0	74	3.64	33.6	37.2	45.73	1289	3296
F $test_{cultivar}$	***	***	***	ns	ns	***	**	***	***
$SE_{cultivar}$	0.421	0.17	0.6	0.709	3.81	1.26	4	61.5	78.8
Combined									
Organic mean	2.74	16.6	70	3.09	31.3	49.8	58.4	1354	3220
Conv. mean	5.02	15.3	73	4.22	32.1	42.3	46.9	1270	3009
F $test_{management}$	*	**	*	ns	ns	ns	ns	ns	ns
$SE_{management}$	0.631	0.24	0.7	0.515	4.36	4.56	4.33	59.1	129.2
F $test_{cultivar}$	***	*	*	ns	***	***	***	**	***
$SE_{cultivar}$	0.467	0.8	0.8	0.523	3.93	3.63	3.63	44.2	97.1
F $test_{m*c}$	**	ns	ns	**	**	***	***	***	***

ns= not significant ($P \geq 0.10$), * significant at $P<0.10$, ** significant at $P<0.05$, *** significant at $P<0.01$, SE=standard error

Organic yields were roughly half of conventional yields (2.74 vs. 5.02 t ha-1, respectively) (Table 1). AC Superb yielded the highest and Marquis the lowest in both systems. Grain protein levels were higher in the organic system compared to the conventional system. Flour yield was significantly higher in the conventional system than the organic system.

In the combined analysis, there were significant management × cultivar interactions for Cu, Mn, Zn, Fe, Mg and K (Table 1). AC Elsa grown conventionally had higher levels of grain Cu than A.C. Elsa, Marquis and Park grown organically. For Zn, Fe and Mg, organic grain had generally higher nutrient levels than conventional grain. Organically grown Glenlea had superior grain Mn, Zn, Fe, Mg and K concentrations to other organically and conventionally grown cultivars.

Cultivars varied significantly ($P<0.05$) for grain Mn, Zn, Fe, Mg and K. Glenlea had the highest grain Zn and Fe contents, while Superb had the highest grain Mn and K contents. Management system had no significant effect on grain nutrient content.

Within the organic system, Glenlea had the highest levels of Zn, Mn, Mg, K and Fe, followed by the most recent cultivars AC Elsa or AC Superb. In the conventional system, a number of different cultivars had the highest levels of grain nutrients (Zn – Marquis, Mg – Park, K - AC Superb and Fe – AC Elsa).

Discussion & Conclusions

There has been a trend towards lower protein in cereal grains produced organically [3]. Applications of composted dairy manure in the organic system (combined with lower yields) appeared to supply nutrients for improved levels of grain protein and nutrient content [5]. However, this experiment demonstrates that both organic and conventional systems can produce high quality wheat.

Significant management × cultivar interaction effects indicate that the choice of wheat cultivar to maximize grain nutrient levels is dependent on the management system. Glenlea grown organically had the highest grain nutrient levels compared to cultivars grown both organically and conventionally.

Both systems of management are capable of producing high quality grains. Wheat cultivar choice within a management system is an important determinant of crop nutritional quality. Further studies are required to determine the impact of other agronomic cropping practices and identify best management practices within organic and conventional systems for final crop quality.

Acknowledgments

We thank Alireza Navabi, Klaus Strenzke and Brenda Frick for technical support. We gratefully acknowledge the financial support of the Natural Sciences and Engineering Research Council, Alberta Ingenuity and the Alberta Crop Industry Development Fund.

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Appendix 6-5. Newspaper article appearing in the Western Producer, 2007, discussing research projects and University of Alberta WISEST program, authored by A. Kornelsen, A. Nelson and D. Spaner.

High School Student Discovers the Benefits of Intercropping

Alana Kornelsen, Alison Nelson and Dean Spaner

At the University of Alberta, high school students are being given a chance to experience University level research. Alana Kornelsen, a grade 12 student at Scona High School in Edmonton, worked with Alison Nelson, a graduate student in the Department of Agricultural, Food and Nutritional Science to investigate ways to suppress weeds without chemicals. This project was part of the Women in Scholarship, Engineering, Science and Technology (WISEST) summer research program.

WISEST is an organization that seeks to increase gender diversity by encouraging women to choose careers in science, engineering, scholarship and technology and men to consider areas of science that are less traditionally male. The Summer Research Program partners young women with researchers (preferably female) in science and engineering. Young men are partnered with researchers in nursing, human ecology and nutrition. This program pairs young women and men in high school with researchers for six weeks. It is designed to show young women and men about science and engineering disciplines that are non-traditional for their gender.

As part of a summer 2006 work experience with the wheat breeding and agronomy program at the University of Alberta, Alana worked alongside Alison to compare monocrops and intercrops for yield and weed biomass in both organic and conventional cropping systems.

The main purpose of the study is to compare soil biological communities of annual intercrops in organic and conventional systems in Alberta. We are interested in comparing soil microbiological diversity under cropping regimes of differing diversity levels. We believe that with greater crop diversity there will be greater soil biological diversity. Soil microbes carry out a number of beneficial functions in cropping systems, including nutrient cycling. Ensuring a diversity of soil microorganisms will help maintain the soil's ability to supply nutrients to crops.

Studying soil microorganisms requires specialized skills and a great investment of time. However, the same intercrops in which we are measuring microbial activity also have weed suppression benefits. Alana’s project measured these benefits during the field season.

Organic farmers differ from conventional farmers in that they do not use herbicides to control weeds. Therefore, an alternative method of weed control is necessary, as competition from weeds pose a significant problem to organic farmers. Even farmers that rely on chemicals for weed control can take advantage of alternative methods. Intercropping is one such method which could be used. Thus, wheat, barley, canola, and peas were planted as monocrops, and in all combinations that included wheat. Because planting several crops together combines their respective competitive traits, such as leaf cover and height, we anticipated lower weed biomass in the intercropped systems. The obvious weed suppression benefits we observed when barley was combined with other crop species in both the organic and conventional systems prompted us to quantify those benefits.

We found that all combinations that included barley had much lower percent weed biomass than the other intercrops tested. In the conventional system, weeds represented 1% of the total biomass in barley plots, while weeds comprised 5 to 22% of the biomass of the other monocrops and the intercrops without barley. In the organic system, the influence of barley was even greater. The barley monocrop and barley-containing intercrops had up to 23% of the total biomass as weeds. This compared to 42-85% of the total biomass as weeds for all the non-barley monocrops and intercrops. Peas did not improve the weed suppression of any combination, but this may be due to low (30 %) emergence in both systems

There are obvious harvest problems still to be worked out with annual intercrops, However, intercropping with wheat, especially when the intercrops include barley, can effectively reduce weed biomass. Organic and conventional farmers may use this technique to effectively manage weeds. The same study will be repeated next summer to facilitate more precise and repeatable results.

This article was guest authored by Alana Kornelsen, Alison Nelson and Dean Spaner. Alana is a grade 12 student at Scona High School in Edmonton, Alison and Dean are from the Department of Agricultural, Food and Nutritional Science at the University of Alberta.

Appendix 6-6. Technical report for the Organic Agriculture Centre of Canada for the 2008 Annual Report.

THE CONNECTIONS BETWEEN WHEAT CULTIVAR CHOICE, BREADMAKING QUALITY AND SOIL MICROBIAL COMMUNITIES

Final Research Report W2008-XX

INTRODUCTION

Consumers are increasingly choosing organic foods, in large part because they perceive organic foods to have superior quality to conventional foods. However, research comparing nutritional and sensory profiles of organic and conventional foods has not yielded consistent results (Bourne and Prescott 2002).

Soil microbial communities play an important role in soil fertility and nutrient cycling, and may affect final crop quality. Microbial communities are affected by production practices such as management system (Bossio et al. 1998) and cultivar choice (Germida and Siciliano 2001).

A study was conducted at the University of Alberta to determine the effect of spring wheat cultivar choice and management system on soil microbial diversity, crop productivity and quality.

WHAT WAS DONE

Six western Canadian spring wheat cultivars (Elsa, Marquis, Park, Glenlea, Go and Superb) were grown at one organically managed, and one conventionally managed field site in 2005 and 2006 in Edmonton, AB.

Research plots at the University of Alberta, Edmonton, AB

Table 1. Breadmaking Quality Measures

Parameter	*Label*	*Importance*	*Standard values*
Grain protein	PRO	Important for gluten formation	over 12%
Flour yield	FLY	Measures milling quality	over 78%
Falling number	FN	Indicates sprouting resistance	over 400
Particle size index	PSI	Indicates kernel hardness	50-55 PSI
Mixing development time	MDT	Time needed to develop the dough	2-3 minutes

Table 2. Least squares means for yield and breadmaking quality measures of wheat grown organically and conventionally in Edmonton, AB

	Yield	PRO	FLY	FN	PSI	MDT
	(t ha^{-1})	(%)	(%)	-	(%)	(min.)
Conventional	5.3	15.1	73	486	52	2.7
Organic	2.1	16.9	70	472	49	2.4
F test mgmt	*	*	NS	NS	NS	NS

NS = non-significant difference, * significance at P<0.10

Soil samples were taken during the growing season, and the soil microbial community was characterized using phospholipid fatty acid analysis (PLFA). Total biomass, % Gram negative, % Gram positive, % fungi, PLFA richness, evenness and diversity were measured on the soil microbes.

Harvested grain was sent to the Cereal Research Center, Agriculture and Agri-Food Canada, for breadmaking quality analysis. Measures taken are listed in Table 1.

WHAT HAPPENED?

Productivity & Breadmaking Quality
Yields under organic management were about half of those under conventional management. Grain protein levels were 12% higher in the organic system compared to the conventional system. Protein content of grain is an important factor in breadmaking quality, and was higher in the organic system. Other experiments have reported protein levels in organic systems to be lower (Poutala et al. 1993) or the same (Ryan et al. 2004) as conventional systems. Lower yields and heavy applications of compost for many years prior to the wheat crops in the organic system may explain the higher protein content in organic wheat. However, this experiment demonstrates that it is possible to have similar protein levels in organic and conventional systems.

The six cultivars differed in all the breadmaking quality measures when compared within the organic and conventional systems separately, however, all quality measures were within standard levels.

Yield differed among the cultivars in the conventional system, but not in the organic system (Table 3).

Soil Microbial Community
In the soil microbial community, cultivar altered the percentage of fungi, PLFA evenness and PFLA diversity in the conventional system. However, cultivar did not affect any of the PLFA measures in the organic system. Management system also did not affect microbes. It appears that factors other than cultivar are important in determining microbial community structure in organic grain production systems.

Grain was harvested from the research plots and sent to Agriculture and Agri-Food Canada for breadmaking quality analysis

Table 3. Least squares means for yield of six wheat cultivars grown organically and conventionally in Edmonton, AB

Cultivar	Conventional Yield ($t\ ha^{-1}$)	Organic Yield ($t\ ha^{-1}$)
Superb	6.0a	2.3ab
Glenlea	5.9ab	2.0ab
Go	5.4ab	2.5ab
Elsa	5.4ab	2.1ab
Park	5.0ab	2.1ab
Marquis	4.4b	2.0ab

Means followed by the same letter are not significantly different (P<0.05)

Associations among Grain Quality and Soil Microbial Community

There were some associations between grain quality and the soil microbial community in both the organic and conventional systems. However, there were more correlations in the organic system. Sixteen of 42 correlations were significant in the organic system (Table 4), and only seven of 42 correlations were significant in the conventional system (data not shown).

The percentage fungi was positively associated with yield under organic management (r=0.9) (Table 4) and under conventional management (r=0.7). A positive association means that as the percentage of fungi in the soil increased, yields did as well. The positive correlation between yield and % fungi may be due in part to mycorrhizal fungi, as mycorrhizae can benefit plant nutrient uptake and crop productivity.

PLFA analysis measures the viable soil microbial biomass, and can be used to characterize the microbial community structure.

More significant relationships between grain quality and soil microbes in the organic system may indicate that soil microbes play a greater role in determining crop quality in the organic system than the conventional system.

Table 4. Correlations of grain breadmaking measures with soil microbial measures in the organic system

	Total biomass	% Gram- bacteria	% Gram+ bacteria	% Fungi	PLFA Richness	PLFA Evenness	PLFA Diversity
Yield	-	-0.68**	-0.60*	0.91**	-0.91**	-0.79**	-0.91**
PRO	-	-	0.58*	-	-	0.56*	0.57*
PSI	-	-	-0.62**	0.70**	-	-0.58*	-0.59*
FN	-	-	-	0.66**	-	-	-
FLY	-	-	-	-	-0.58*	-	-
MDT	-	-	0.67**	-	-	-	-

*, ** denotes r values significant at P<0.10, P<0.05, respectively. - denotes no significant correlation (P>0.10)

THE BOTTOM LINE...

Yields were lower in the organic system, but protein levels and breadmaking quality at least equal to conventional systems can be achieved in organic systems.

Cultivar choice altered grain quality and yield in both systems, however, quality measures all fell within standard levels. Cultivar did not have an effect on soil microbial communities in the organic system, indicating that something other than cultivar is affecting the structure of the microbial community.

Soil microbes may play a greater role in determining crop quality in organic systems than in conventional systems.

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ACKNOWLEDGEMENTS

Thanks to Klaus Strenzke, Alireza Navabi, Dave Nizol and others for technical and scientific assistance.

CREDITS

Alison Nelson (graduate student, University of Alberta), Dean Spaner (University of Alberta) and Brenda Frick (Organic Agriculture Centre of Canada)

FUNDING

Alberta Crop Industry Development Fund
Alberta Ingenuity
Natural Sciences and Engineering Research Council
Organic Agriculture Centre of Canada

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