ORGANIC CONSERVATION TILLAGE PRODUCTION SYSTEMS IN THE PALOUSE

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Abstract

Organic, reduced-till (ORT) dryland cropping systems show potential for economic viability while meeting soil health and conservation needs in the hilly, highly erodible Palouse soils of northern Idaho and eastern Washington. To investigate impacts on soil health, we measured chemical, physical and biological indicators in replicated plots allocated to two ORT cropping systems and one non-organic no-till system after five years of crop rotations. Positive changes in biological and chemical properties were observed under organic compared to conventional management, while physical properties remained similar despite greater disturbance in the organic systems. Based on ORT research trials, economic feasibility was assessed through a cost of production analysis for integrating 100 acres of ORT crop production into a 2,000 acre non-organic dryland farm. A five-year alfalfa-wheat and a three-year wheat-pea hay crop rotation show potential for economic profitability. Field scale research is suggested before ORT practices are suggested for regional commercial operations.

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Dedication

I would like to thank my parents, Gail and Rick, and my partner Ryan for their support and encouragement throughout this process. I would also like to thank my friend Nora, for always insisting that I keep things in perspective.

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1.1 Introduction

Environmental concerns have increased demand for sustainable land management, and in particular, the preservation of agricultural soil health (Doran and Zeiss, 2000). To meet this goal, farmers must balance productivity and yield with the need to maintain healthy soil ecosystem function (Doran and Zeiss, 2000). This coincides with a call to develop longer-term sustainable cropping systems in the Western U.S. (Rasmussen et al., 2013). In the Palouse region of the Inland Pacific Northwest, improved crop breeding and nutrient and pest management technologies have increased yields of dryland crops, though the success has concealed coinciding soil degradation (McCool et al., 2001). Soil acidification from the use of synthetic fertilizers and high soil erosion rates from intensive tillage are two of the main threats to soil health and crop production (McCool et al., 2001) in this historically high yielding wheat production region (Hall et al., 1999). Soil conservation efforts in the Palouse have focused on reducing soil erosion through the adoption of no-till practices (Papendick, 1996; Kok et al., 2009). Organic dryland wheat production is scarce in the Palouse (Jones et al., 2006), possibly due to the overriding need to prevent soil erosion (McCool et al., 2001) and the challenges associated with weed control when combining reduced-tillage with organic management (Peigné et al., 2007).

Organic farming practices have been linked to improvements in soil quality (Reganold, 1988; Mäder et al., 2002; Fließbach et al., 2007), though it is questioned whether organic cropping systems are more sustainable than those managed by conventional no-till practices (Trewavas, 2004). Research from the last decade indicates that reduced tillage within organic management systems improves near-surface soil health, particularly in terms of soil organic carbon and microbial biomass (Berner et al., 2008; Gadermaier et al., 2012), as well as enzyme activity, plant nutrients, potentially mineralizable nitrogen (PMN), and earthworm abundance (Carr et al., 2013). Few have compared organic, reduced-till (ORT) to conventional, no-till (CNT). In the short-term (four years) higher levels of PMN (Miller et al., 2008), and earthworm density (Crittenden et al., 2014) have been reported in ORT compared to CNT systems. However, after three years of tillage trials in organic systems, bulk density was higher under reduced tillage than moldboard plowed soils (Peigné et al., 2009). It has been suggested that longer time periods (>3 years) may be required for changes in soil physical properties to occur (Peigné et al., 2009; Johnson-Maynard et al., 2007). Organic farmers are encouraged to adopt reduced tillage practices to prevent long-term soil degradation from erosion and compaction (Peigné et al., 2007), and agricultural practices that support long-term soil health in general should be a high priority among farmers and researchers. Trewavas (2004) suggested that management quality is more important than adhering to conventional or organic methods of agriculture, and that high quality management requires adaptability and an understanding of the interconnected, systems-nature of a farm. While organic management may not be a practical option for all agroecosystems or production scenarios, diversified crop rotations (Stockdale et al., 2001; Miller et al., 2013) and greater drought tolerance (Lotter et al., 2000), coupled with improved crop breeding (Stockdale et al., 2001; Murphy et al., 2007) and management strategies (Carr et al., 2011), may make it appropriate for a growing range of climate and ecosystem conditions (Borron, 2006; Scialabba and Müller-Lindenlauf, 2010). The feasibility of ORT management for Palouse dryland systems, and the progress of dryland ORT research are discussed below.

Organic, reduced-tillage methods range in intensity and soil disturbance levels across climatic zones and soil types. Much of the research in rain-fed ORT systems originated in Europe where the focus has been to reduce the depth and intensity of inversion tillage, whereas in North America there is more emphasis on eliminating inversion tillage practices to conserve soil resources (Carr et al., 2012). In place of tillage for weed control in ORT systems, a common strategy in the U.S. includes terminating cover crops to create weed suppressive mulches, which has been executed with a range of success (Carr et al., 2012). Studies in the Palouse have applied reduced-tillage strategies similar to those used in regional non-organic systems, utilizing a rotary hoe, harrow and undercutter, all of which restrict soil disturbance to relatively shallow depths, and retain plant litter on the soil surface (Gallagher et al., 2010; Borrelli et al., 2012). Despite concerns over soil erosion and health within the Palouse, few studies have focused on the impacts of organic dryland crop rotations, fertilizer, and low disturbance tillage treatments on yield and soil fertility. These past studies focused on the transition to ORT management and early years of production (Gallagher et al., 2010; Borrelli et al., 2012). The long-term success of these systems is unknown.

1.2 Agronomic Factors in ORT

To achieve crop productivity, organic agriculture relies more heavily on natural soil ecosystem processes than do conventional systems (Fließbach et al., 2007). In organic systems, the uptake of nutrients by crops depends on soil biological and chemical processes to convert organic materials into plant available forms to a greater extent than in conventional systems (Drinkwater et al., 1998; Mäder et al., 2002; Fließbach et al., 2007; Stockdale and Watson, 2009). This is largely due to the predominant use of slow release nutrient sources in organic agriculture (Stockdale and Watson, 2009). Minimizing tillage in organic agricultural systems may further slow nutrient cycling processes, adding to the challenge of building soil fertility and maintaining yields (Berner et al., 2008; Gallagher et al., 2010). Further investigation of management impacts on soil health under ORT may help overcome some of these challenges.

The combined use of competitive crop rotations and shallow tillage implements to control weeds are important to the success of ORT systems (Gallagher et al., 2010). Diverse crop rotations provide and balance soil nutrients (Grant et al., 2002), break disease cycles (Francis and Clegg, 1990), and are an important strategy for weed control, particularly in organic systems (Anderson, 2010). The inclusion of legume crops is considered essential in ORT systems (Gallagher et al., 2010) due to their positive impacts on soil nitrogen, soil structure, and other aspects of soil health (Peoples et al., 2009). Perennial-legume crops in particular are suggested to be highly important in ORT systems (Gadermaier et al., 2012), for benefits to soil structure (Peigné et al., 2007), and nutrient cycling and weed suppression (Peigné et al., 2007; Anderson, 2010); however, their removal using minimum tillage implements can be a challenge. Gallagher et al. (2010) found a fall undercutter plus rotary harrow method was successful in terminating a perennial alfalfa crop at the end of an organic transition period. Krauss et al. (2010) successfully removed a grass-clover ley crop with a chisel plow (15 cm), and a stubble cleaner (undercuts and mixes the top 5 cm). Though nutrient uptake, yield, and presumably soil moisture retention was greater in reduced-tillage treatments, weed infestation and disruption to arbuscular mycorrhizal fungi (used as an indicator of disturbance) was also greater using this minimum-till method compared to moldboard plowing to 15 cm (Krauss et al., 2010). Furthermore, weed pressure remains a prominent obstacle for adaption of ORT practices, despite advances in reduced-tillage practices (Mäder and Berner, 2012). Overcoming these challenges is critical to the success of ORT cropping systems.

1.3 Soil Properties in ORT

ORT research suggests improvements to soil properties compared to non-organic reduced-tillage. Trends of increased soil biological activity (Mäder et al., 2002) and soil organic carbon (SOC) (Reganold, 1988; Drinkwater et al., 1998) are often observed in studies comparing organic to non-organic agricultural soils. This mirrors trends of increased biological activity and SOC accumulation in reduced-till compared to conventional-till soils (Chan, 2001; Purakayastha et al., 2009; Castellanos-Navarrete et al., 2012). Soil organic carbon increased by 7.4% after three years (Berner et al., 2008) and 19% after six years (Gadermaier et al., 2012) under reduced-tillage compared to no change under moldboard plowing in organically managed soils (0 – 10 cm), and was greater in ORT soils (19.2 g kg^{-1}) compared to non-organic no-till soils (15.5 g kg^{-1}) in the top 10 cm (Teasdale et al., 2007). Microbial biomass carbon (MBC) and nitrogen (MBN) also increased significantly under ORT compared to moldboard plowed organic soils by 37% (MBC) and 35% (MBN) (Gadermaier et al., 2012). Similar trends in microbial biomass were also reported by Emmerling (2007) and Berner et al. (2008).

Research regarding physical properties in ORT soils reports mixed results. Vakali et al. (2011) reported a 46% increase in aggregate stability (0-15 cm soil) of reduced-tillage (non-inversion) compared to moldboard plow treatments after seven years of organic management in a clay loam in Germany. Similarly, Emmerling (2007) found greater aggregate stability in ORT soils, which was correlated to microbial biomass and SOC, compared to moldboard plow organic treatments after four years. However, significantly higher bulk density was found under reduced-tillage treatments in this study (Emmerling, 2007). Conversely, Peigné et al. (2009) reported no measurable improvements to soil structure after 6 years of ORT. Despite increases in earthworm populations in the reduced tillage soils, moldboard plowed soils had lower bulk density in the 15 – 30 cm depth (1.45 Mg m^{-3}, site A; 1.24 site B), than did reduced-tillage soils (1.60 Mg m^{-3}, Site A, 1.28 Site B), supported by greater porosity in moldboard plowed compared to reduced-till soils. Relative to soil biological and chemical properties, longer time intervals may be necessary to observe changes to soil physical properties.

Soil biological communities generally respond rapidly to agronomic practices, and are important in building soil health. Earthworm populations in no-till soils were 4x greater after 4 years (Castellanos-Navarrete et al., 2012) and 3.4 - 4.0x greater after 3 years (Johnson-Maynard et al., 2007) compared to plowed soils (disc plowed and chisel plowed, respectively). In reduced tillage systems, earthworms may be of greater importance to soil functions compared to intensive tillage systems because of their contributions to soil fertility, nutrient cycling and soil structure (Chan, 2001). Considered “ecosystem engineers” (Lavelle, 1997), earthworms impact soil structure, water infiltration, aeration, and soil organic matter decomposition (Lee, 1995). However, their impact varies among different earthworm functional groups and agricultural methods (Keith and Robinson, 2012). For instance, endogeic earthworm species live in organo-mineral horizons, build horizontal burrows, and feed on soil enriched in organic matter, while anecic species are surface feeders that build deep vertical burrows (Lee, 1995). Resulting from behavioral differences among these functional groups, moldboard plowing tends to support endogeic species and reduce anecic species (Ernst and Emmerling, 2009). Thus, no change or an increase in earthworm abundance due to reduced tillage has been observed in non-organic systems, largely where endogeic species are present and when tillage incorporates organic matter into the soil profile (Chan, 2001). The size of an earthworm population dominated by anecic species did not increase when tillage depth was decreased in an organic system (Metzke et al., 2007). Differing reports in the literature are likely an effect of differences in earthworm species, soil environmental conditions, and the level of disturbance from tillage practices among the studies.

Tillage impacts earthworms by altering their physical habitat and the availability of food (Chan, 2001); the relative magnitude of the effect that different types of tillage have on soil environmental conditions likely influences the overall effect on earthworm populations. For instance, vertical stratification of SOC (food) that occurs in soils managed by conservation tillage increases earthworm biomass and species richness (Ernst and Emmerling, 2009). Furthermore, tillage can affect earthworms differently in organic and non-organic soils (Crittenden et al., 2014), where the abundance of organic matter (i.e., food source) is typically greater in organic systems (Reganold, 1988). Different results reported for the impact of ORT methods on earthworm population size may be due to an increase of anecic species (Peigné et al., 2009), or decline of endogeic species (Crittenden et al., 2014). In Palouse arable lands, earthworm populations are dominated by an endogeic species, *Aporrectodea trapezoides*, (Fauci and Bezdicek, 2002; Johnson-Maynard et al., 2007; Umiker et al., 2009). In contrast to the results of Crittenden et al., (2014), who reported no difference in tillage treatment effects on endogeic species in non-organic systems after four years, endogeic species (*A. trapezoides)* populations increased in Palouse agricultural soils after three years of no-till practices in non-organic systems (Johnson-Maynard et al., 2007). Conflicting results of ORT on earthworm populations suggest differences in soil environmental conditions that may be influenced by agricultural management are likely at play.

1.4 Yield and economic potential of ORT systems

In addition to maintaining soil health, ORT methods must also achieve profitable and competitive yields to be sustainable and to meet societal food demand. Organic production is sometimes viewed as a threat to food security because it is often associated with decreased yields (Connor, 2008). This view is supported by a meta-analysis study of over 350 published articles that reports average organic yields to be 80% of conventional yields, though with a 21% standard deviation (de Ponti et al., 2012). Large variation in yield potential is indicative of the diversity in organic farming, and correspondingly the challenge of accurately assessing production potential at a large scale. Additionally, research suggests greater resilience of organic crops during drought years (Pimentel et al., 2005), coupled with improved soil health (Mäder et al., 2002) that may have important implications on long-term production capacity.

In the last decade, crop yields under organic management, in general, have improved (Pimentel et al., 2005), and certain crops have emerged as being better suited for organic production than others. For instance, organic wheat and alfalfa yields are reported to be competitive with non-organic production capacity in systems that use tillage (Wortman et al., 2011). Yields can be significantly lower in ORT systems compared to non-organic systems, yet ORT management resulted in greater soil N availability in the long-term (after 9 years) (Teasdale et al., 2007). Winter wheat (Miller et al., 2008), and grass-clover forage (Krauss et al., 2010) appear to have better competitive ability than other crops under ORT management, yielding equal to or exceeding non-organic reduced-till yields, while barley and other spring crops tend to be less competitive (Gallagher et al., 2010; Borrelli et al., 2012). The role of organic dryland grains (particularly wheat) and forage (particularly alfalfa) will be further discussed due to their relative success under organic management and their relevance to regional Palouse agricultural systems.

Added risks and uncertainties are associated with organic production. Yield and price premiums determine the profitability of organic crop production, both factors being highly variable (Smith et al., 2004). Analysis of the 2009 Agriculture Resource Management Survey (ARMS) shows average organic wheat premiums \$3.79 bu^{-1} over non-organic prices. This resulted in positive net returns over total costs (TC= operating + capital costs) \$2.18 bu^{-1} higher than non-organic wheat due to the higher organic price premium, despite consistently lower yields reported by commercial organic producers (McBride et al., 2012). Differences in production costs are also important to consider. In this study, organic wheat operating costs were \$0.33 bu^{-1} lower than non-organic, though total costs were \$1.61 bu^{-1} higher and economic costs were \$3.96 bu^{-1} higher than that of non-organic prices (McBride et al., 2012). This analysis of commercial production practices shows that profitability of organic production is dependent on availability of organic price premiums. By contrast, field trial research from the Northern Great Plains shows that organic wheat-based cropping systems can produce similar net returns to some non-organic systems with low and no organic price premiums (Smith et al., 2004). However, high organic price premiums were required to match the most profitable non-organic system of continuous no-till wheat (Smith et al., 2004). Receiving organic price premiums is not guaranteed and must be considered when assessing risk. For instance, a survey of Idaho organic farmers reports that about 30% of growers sold all their organic crops at organic premium prices, and 40% were able to sell only half (Goldberger et al., 2010). While these survey results reflect the scenario from one year only, it demonstrates the non-uniform availability of organic price premiums.

Profitability of organic farming systems is highly variable, though many studies show greater net returns of organic over non-organic grain production (Delate et al., 2003; Delbridge et al., 2013). However, studies often assume that machinery ownership and overhead costs are the same in organic and non-organic farm systems, which may underestimate costs of organic production and ignores differences in farm size that may be required to meet the management costs of each system (Delbridge et al., 2013). A whole-farm systems study in Minnesota found that organic systems were limited to smaller acreage in order to achieve acceptable profitability given medium (227 ha) and large (324 ha) machinery complement scenarios, compared to the acreage potential for non-organic systems (medium=356 ha, large=550) (Delbridge et al., 2013). Yet, despite smaller acreage, average whole-farm net returns were greater for organic than for non-organic given each machinery complement scenario (Delbridge et al., 2013). Results of the 2009 ARMS, as discussed above, show positive returns over TC but not over total economic costs (-$0.17) (McBride et al., 2012). Higher economic costs in this study are indicative of greater opportunity costs to labor and land, and additional overhead as reported by producers (McBride et al., 2012). However, the range and complexity inherent in organic management practices and the adjustment period when adapting a new farm system can result in a wide range of yield capabilities among growers (Delbridge et al., 2013), which are also important factors when comparing economic costs. For these reasons, analysis of organic crop profitability must be measured at an appropriate scale and consider whole-farm viability. In the Palouse, organic production may be most profitable when conducted on a limited number of acres of a larger non-organic farm, where machinery costs could be distributed between both production systems.

1.5 Marketing organic crops

Organic crop production generally requires greater involvement in the marketing process than sales to conventional commodity markets. Furthermore, there is greater risk and higher costs associated with marketing organic crops (Smith et al., 2004). Labor and management costs for organic crops are reported by growers to be 30% – 40% greater than for conventional production, a significant portion of which is attributed to marketing needs (Miller et al., 2008). Idaho farmers use a variety of marketing channels to sell organic crops (including vegetables, grains, forage, dairy, etc.), including whole sale, and direct-to-consumer, and direct-to-retail avenues (Goldberger et al., 2010). While the majority of Idaho organic products are marketed locally (less than 100 miles), regional and national markets are also used (Goldberger et al., 2010). Some of the risk and price fluctuations may be alleviated through marketing contract arrangements; however, only about one-third of Idaho certified organic producers sell under these contracts, and it is not common in the northern region of the state (Goldberger et al., 2010). Similar marketing attributes are reported for Washington organic growers as well (Goldberger et al., 2010). The greater effort required for marketing is incentivized by high national demand for organic crops and their large profit potential.

1.6 Supply and demand trends for organic crops

Dryland organic crop production is a small portion of the Inland Pacific Northwest agricultural economy, representing less than 0.01% of organic dryland acreage in eastern WA (Kirby and Granatstein, 2014; USDA-NASS, 2014a), though national trends suggest growth potential. Across the U.S., organic cropland increased by 16% from 2008 to 2011, reaching approximately 3.1 million acres in 2011 (USDA-ERS, 2013a). There are approximately 5.5 million acres in WA and 2.5 million in ID dedicated to dryland crops (Schillinger et al., 2003). In terms of all forms of agricultural production, 92,000 acres in WA and 116,000 in ID were certified organic in 2011(USDA-ERS, 2014a; b). Organic production is thus a small subset of the larger regional agricultural industry.

National consumer demand for organic foods has increased over the past few decades, outpacing supply (Greene et al., 2009). Total national organic food sales increased from $3.6 billion in 1997 to $21.1 billion in 2008 (Greene et al., 2009). As of 2008, organic foods accounted for 3% of total U.S. food sales, with about 69% of U.S. consumers reporting at least occasional annual organic food purchases (Greene et al., 2009). The large percentage of the U.S. population that purchases organic foods may be due to the expansion of organic food outlets to include mainstream supermarkets and big-box store outlets such as Wal-Mart and Costco (Greene et al., 2009), where approximately half of organic food items are purchased (Dimitri and Oberholtzer, 2009).

Despite national growth trends, 65% of Idaho organic producers report “limited demand for organic products” as a challenge, though this perception varies throughout the state (Goldberger et al., 2010). This study included producers of all organic crops (forage, grains, oilseeds, vegetables, potatoes, berries, dry beans and peas, cattle, dairy, etc.), and grower perceived demand for individual crops may vary. The disconnect between national high demand trends and a perception of limited regional demand by organic growers suggest that barriers to organic production and market access have an overriding effect. Additionally, this highlights a need for better information about market trends, or improved facilitation between growers and buyers. For instance, national growth in organic dairy and meat production has increased demand for feed grains (Dimitri and Oberholtzer, 2009). With regional growth in the organic dairy industry in Southern Idaho and parts of Oregon and Washington occurring in 2005 - 2006, there was potential for growth in organic feed grains and forages markets (Painter et al., 2007). Three years later a survey found that Idaho growers still perceived a lack of demand, suggesting saturation of the regional market or that factors are limiting the ability of growers to sell feed grains within the region. Perceptions and demand may have changed, but current information is unavailable.

Forage, grains and oilseeds are among the most common organic crops grown in Idaho. However, they are mainly produced in the eastern and southern regions of the state (Goldberger et al., 2010). In Washington, forage accounts for approximately 31% and grains, dry beans and oilseeds for 9% of total organic crop production (Kirby and Granatstein, 2009). Nationally, organic wheat acreage increased by 10% to 12% annually between 2000 and 2005 (Dimitri and Oberholtzer, 2009), and organic wheat production in the Pacific Northwest specifically has continued to grow in more recent years. From 2006 to 2011, organic wheat acreage increased by 78% in WA and 24% in ID, bringing the total acreage for both states to 15,400 acres in 2011 (USDA-ERS, 2013a).

1.7 Study objectives

This study analyzes soil health and economic aspects of ORT cropping systems to assess their potential for use in the Palouse region. Soil biological, chemical, and physical properties were measured after 10 years of organic cropping system trials. The most recent six years of this study included non-organic reduced tillage systems trials for comparison to the organic trials. The overall objective is to observe how crop systems affect soil properties, and if differences in soil health and economic returns emerge after 10 years of production. Soil analysis will focus on three crop rotations, an organic 5-year alfalfa-wheat based system, a 3-year organic wheat-legume based system, and a 3-year conventional wheat-legume based system. Economic analysis will consider two additional organic cropping systems (total of 4) and two non-organic systems.

Objectives of the soil analysis are to:

1. Determine if cropping systems impact biological, physical and chemical indicators of soil health after 10 years of ORT management
2. Assess the relationships among the selected soil health indicators and yield.

The objectives of the economic analysis are to:

1. Investigate market potential for organic dryland crops grown in the Palouse, and through literature review, assess the status of organic dryland crop production in the Inland Pacific Northwest.
2. Develop appropriate scale economic budgets for ORT management in the Palouse, based on soil and yield analyses from long-term research plots.

1.8 References

Anderson, R.L. 2010. A rotation design to reduce weed density in organic farming. Renew. Agric. Food Syst. 25(3): 189–195.

Berner, A., I. Hildermann, A. Fließbach, L. Pfiffner, U. Niggli, and P. Mader. 2008. Crop yield and soil fertility response to reduced tillage under organic management. Soil Tillage Res. 101(1-2): 89–96.

Borrelli, K., R. Koenig, R.S. Gallagher, D. Pittmann, A. Snyder, I. Burke, L. Hoagland, and E.P. Fuerst. 2012. Alternative strategies for transitioning to rrganic production in direct-seeded grain systems in eastern Washington II: Nitrogen fertility. J. Sustain. Agric. 36(4): 461–477.

Borron, S. 2006. Building resilience for an unpredictable future: How organic agriculture can help farmers adapt to climate change. Rome, August 2006. Rome.

Carr, P.M., R.L. Anderson, Y.E. Lawley, P.R. Miller, and S.F. Zwinger. 2011. Organic zero-till in the northern US Great Plains Region: Opportunities and obstacles. Renew. Agric. Food Syst. 27(01): 12–20.

Carr, P., G. Gramig, and M. Liebig. 2013. Impacts of organic zero tillage systems on crops, weeds, and soil quality. Sustainability 5(7): 3172–3201.

Carr, P.M., P. Mäder, N.G. Creamer, and J.S. Beeby. 2012. Editorial: Overview and comparison of conservation tillage practices and organic farming in Europe and North America. Renew. Agric. Food Syst. 27(01): 2–6.

Castellanos-Navarrete, A., C. Rodríguez-Aragonés, R.G.M. de Goede, M.J. Kooistra, K.D. Sayre, L. Brussaard, and M.M. Pulleman. 2012. Earthworm activity and soil structural changes under conservation agriculture in central Mexico. Soil Tillage Res. 123: 61–70.

Chan, K.Y. 2001. An overview of some tillage impacts on earthworm population abundance and diversity - implications for functioning in soils. Soil Tillage Res. 57: 179–191.

Connor, D.J. 2008. Organic agriculture cannot feed the world. F. Crop. Res. 106(2): 187–190.

Crittenden, S.J., T. Eswaramurthy, R.G.M. De Goede, L. Brussaard, and M.M. Pulleman. 2014. Effect of tillage on earthworms over short- and medium-term in conventional and organic farming. Appl. Soil Ecol.

Delate, K., M. Duffy, C. Chase, A. Holste, H. Friedrich, and N. Wantate. 2003. An economic comparison of organic and conventional grain crops in a long-term agroecological research (LTAR) site in Iowa. Am. J. Altern. Agric. 18(2): 59–69.

Delbridge, T. a., C. Fernholz, R.P. King, and W. Lazarus. 2013. A whole-farm profitability analysis of organic and conventional cropping systems. Agric. Syst. 122: 1–10.

Dimitri, C., and L. Oberholtzer. 2009. Marketing U.S. organic goods: Recent trends from farms to consumers.

Doran, J.W., and M.R. Zeiss. 2000. Soil health and sustainability: managing the biotic component of soil quality. Appl. Soil Ecol. 15(1): 3–11.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396(November).

Emmerling, C. 2007. Reduced and conservation tillage effects on soil ecological properties in an organic farming system. Biol. Agric. Hortic. 24(4): 363–377.

Ernst, G., and C. Emmerling. 2009. Impact of five different tillage systems on soil organic carbon content and the density, biomass, and community composition of earthworms after a ten year period. Eur. J. Soil Biol. 45(3): 247–251.

Fauci, M.F., and D.F. Bezdicek. 2002. Lumbricid earthworms in the Palouse region. Northwest Sci. Notes 76(3).

Fließbach, A., H.-R. Oberholzer, L. Gunst, and P. Mäder. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118: 273–284.

Francis, C.C., and M.D. Clegg. 1990. Crop rotations in sustainable production systems. p. 107–122. *In* Edwards, C.A., Lal, R., Madden, P., Miller, R.H., House, G. (eds.), Sustainable Agricultural systems. Soil and Water Conservation Society, Ankeny, IA.

Gadermaier, F., A. Berner, A. Fließbach, J.K. Friedel, and P. Mäder. 2012. Impact of reduced tillage on soil organic carbon and nutrient budgets under organic farming. Renew. Agric. Food Syst. 27(01): 68–80.

Gallagher, R.S., D. Pittmann, A.M. Snyder, R.T. Koenig, E.P. Fuerst, I.C. Burke, and L. Hoagland. 2010. Alternative strategies for transitioning to organic production in direct-seeded grain systems in eastern Washington I: Crop agronomy. J. Sustain. Agric. 34(5): 483–503.

Goldberger, J.R., S. Connor, and J. Miller. 2010. The experiences and perspectives of Idaho's certified organic producers: Results from a statewide survey. Sustain. Pacific Northwest 8(2): 8 – 11.

Grant, C.A., G.A. Peterson, and C.A. Campbell. 2002. Nutrient considerations for diversified cropping systems in the Northern Great Plains. Agron. J. 94(March-April 2002): 186–198.

Greene, C., C. Dimitri, B.-H. Lin, W. McBride, L. Oberholtzer, and T. Smith. 2009. Emergying issues in the U.S. organic industry. Econ. Inf. Bull. Number 55.

Hall, M., D.L. Young, and D.J. Walker. 1999. Agriculture in the Palouse: A portrait of diversity.

Johnson-Maynard, J.L., K.J. Umiker, and S.O. Guy. 2007. Earthworm dynamics and soil physical properties in the first three years of no-till management. Soil Tillage Res. 94(2): 338–345.

Jones, S.S., K.K. Kidwell, J. Dawson, R.A. Jussaume, J. Goldberger, R. Krebill-Prather, and L. Glenna. 2006. Wheat production in Washington, Washington State University Summary Report CSS Information Series No. 1202-06. (November)Available at http://www.crs.wsu.edu/wheatproduction/index.html (verified 20 December 2012).

Keith, A.M., and D.A. Robinson. 2012. Earthworms as natural capital: Ecosystem service providers in agricultural soils. Econ. J. 2(Year 2).

Kirby, E., and D. Granatstein. 2009. Profile of organic crops in Washington State – 2008. Wenatchee, WA.

Kirby, E., and D. Granatstein. 2014. Certified Organic Acreage and Sales in Washington State: 2013, Organic Trends series. Wenachee, WA.

Kok, H., R.I. Papendick, and K.E. Saxton. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. J. Soil Water Conserv. 64(4): 253–264.

Krauss, M., A. Berner, D. Burger, A. Wiemken, U. Niggli, and P. Mäder. 2010. Reduced tillage in temperate organic farming: implications for crop management and forage production. Soil Use Manag. 26(1): 12–20.

Lavelle, P. 1997. Faunal activities and soil processes: Adaptive strategies that determine ecosystem function. Adv. Ecol. Res.: 93–132.

Lee, K.E. 1995. Earthworms and sustainable land use. p. 215–234. *In* Hendrix, P.F. (ed.), Earthworm Ecology and Biogeography in North America. Lewis Publishers, Ann Arbor.

Lotter, D.W., R. Seidel, and W. Liebhardt. 2003. The performance of organic and conventional cropping systems in an extreme climate year. Am. J. Altern. Agric. 18: 1–9.

Mäder, P., and A. Berner. 2012. Development of reduced tillage systems in organic farming in Europe. Renew. Agric. Food Syst. 27(01): 7–11.

Mäder, P., A. Fließbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296(5573): 1694–7.

McBride, W.D., C. Greene, M. Ali, and L. Foreman. 2012. The structure and profitability of organic field crop production: The case of wheat. *In* Selected Paper for the Agricultural and Applied Economics Association's 2012 Annual Meeting, August 12-14, 2012. Seattle, Washington.

McCool, D.K., D.R. Huggins, K.E. Saxton, and A.C. Kennedy. 2001. Factors affecting agricultural sustainability in the Pacific Northwest , USA: An overview. p. 255–260. *In* Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Metzke, M., M. Potthoff, M. Quintern, J. Heß, and R.G. Joergensen. 2007. Effect of reduced tillage systems on earthworm communities in a 6-year organic rotation. Eur. J. Soil Biol. 43: S209–S215.

Miller, M., M. Anderson, C.A. Francis, C. Kruger, C. Barford, J. Park, and B.H. Mccown. 2013. Critical research needs for successful food systems adaptation to climate change. 3(4): 161–175.

Miller, P.R., D.E. Buschena, C. a. Jones, and J. a. Holmes. 2008. Transition from intensive tillage to no-tillage and organic diversified annual cropping systems. Agron. J. 100(3): 591–599.

Murphy, K.M., K.G. Campbell, S.R. Lyon, and S.S. Jones. 2007. Evidence of varietal adaptation to organic farming systems. F. Crop. Res. 102(3): 172–177.

Painter, K., D. Granatstein, E. Kirby, and L. Carpenter-Boggs. 2007. Research brief: Market and opportunities for organic feed production in eastern Washington. Sustain. Pacific Northwest Newsl. Vol. 5 No. 1 5(1).

Papendick, R.I. 1996. Farming systems and conservation needs in the Northwest Wheat Region. Am. J. Altern. Agric. 11: 52–57.

Peigné, J., B.C. Ball, J. Roger-Estrade, and C. David. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Manag. 23(2): 129–144.

Peigné, J., M. Cannavaciuolo, Y. Gautronneau, a. Aveline, J.L. Giteau, and D. Cluzeau. 2009. Earthworm populations under different tillage systems in organic farming. Soil Tillage Res. 104(2): 207–214.

Peoples, M.B., D.F. Herridge, B.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khans, B.S. Jensen, P. Industry, G.P.O. Box, S. Asia, S. Asia, S. Asia, S. Asia, S. Asia, and S. Asia. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48: 1–17.

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55(7): 573–582.

De Ponti, T., B. Rijk, and M.K. van Ittersum. 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108: 1–9.

Purakayastha, T.J., J.L. Smith, and D.R. Huggins. 2009. Microbial biomass and N cycling under native prairie, conservation reserve and no-tillage in Palouse soils. Geoderma 152(3-4): 283–289.

Rasmussen, V.P., S. Clary, A. Kurki, and R. Daines. 2013. The next food systems agenda: A western grassroots perspective. J. Agric. Food Syst. Community Dev. 3(4): 235–247.

Reganold, J.P. 1988. Comparison of soil properties as influenced by organic and conventional farming systems. Am. J. Altern. Agric. 3(4): 144–145.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2003. Dryland Cropping in the Western United States. *In* Pacific Northwest Conservation Tillage Systems Handbook Series No. 28.

Scialabba, N.E.-H., and M. Müller-Lindenlauf. 2010. Organic agriculture and climate change. Renew. Agric. Food Syst. 25(02): 158–169.

Smith, E.G., M. Jill Clapperton, and R.E. Blackshaw. 2004. Profitability and risk of organic production systems in the northern Great Plains. Renew. Agric. Food Syst. 19(03): 152–158.

Stockdale, E.A., N.H. Lampkin, M. Hovi, R. Keatinge, E.K.M. Lennartsson, D.W. Macdonald, S. Padel, F.H. Tattersall, M.S. Wolfe, and C.A. Watson. 2001. Agronomic and environmental implications of organic farming systems. Adv. Agron. 70: 261–327.

Stockdale, E.A., and C.A. Watson. 2009. Biological indicators of soil quality in organic farming systems. Renew. Agric. Food Syst. 24(4): 308–318.

Teasdale, J.R., C.B. Coffman, and R.W. Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J. 99: 1297–1305.

Trewavas, A. 2004. A critical assessment of organic farming-and-food assertions with particular respect to the UK and the potential environmental benefits of no-till agriculture. Crop Prot. 23(9): 757–781.

Umiker, K.J., J.L. Johnson-Maynard, T.D. Hatten, S.D. Eigenbrode, and N. a. Bosque-Pérez. 2009. Soil carbon, nitrogen, pH, and earthworm density as influenced by cropping practices in the Inland Pacific Northwest. Soil Tillage Res. 105(2): 184–191.

USDA-ERS. 2013. Organic Production. Available at http://www.ers.usda.gov/data-products/organic-production.aspx#25766 (verified 5 July 2014).

USDA-ERS. 2014a. State Fact Sheets: Idaho. Available at http://www.ers.usda.gov/data-products/state-fact-sheets.aspx#.U3_fPi_lf1s (verified 10 April 2014).

USDA-ERS. 2014b. State Fact Sheets: Washington. : 2–7Available at http://www.ers.usda.gov/data-products/state-fact-sheets.aspx#.U3_fPi_lf1s (verified 10 April 2014).

USDA-NASS. 2014. 2012 Census of Agriculture: Washington State and County Data, Volume 1, Geographic Area Series Part 47.

Vakali, C., J.G. Zaller, and U. Köpke. 2011. Reduced tillage effects on soil properties and growth of cereals and associated weeds under organic farming. Soil Tillage Res. 111(2): 133–141.

Wortman, S.E., T.D. Galusha, S.C. Mason, and C. a. Francis. 2011. Soil fertility and crop yields in long-term organic and conventional cropping systems in Eastern Nebraska. Renew. Agric. Food Syst. 27(03): 200–216.

Chapter 2: Soil health in Palouse organic reduced tillage agricultural systems

2.1 Introduction

Soil health, defined by the soil's ability to function as a living system and maintain biological productivity and environmental quality, is an important factor in determining the resiliency of agroecosystems (Doran and Zeiss, 2000). The concept of soil health encompasses four main functions including nutrient cycling, carbon transformations, development and maintenance of soil structure, and disease and pest regulation (Kibbkewhite, 2008), all of which can be impacted by management practices. Organic management, which restricts the use of synthetic fertilizers and pesticides, has been shown to positively impact many indicators of soil health (Reganold, 1988; Mäder et al., 2002; Stockdale and Watson, 2009; Wortman et al., 2011). One problem related to organic management, however, is the use of tillage to control weeds (Peigne et al., 2007). Overtime, tillage may degrade physical indicators of soil quality and restrict adoption of organic farming systems, especially in areas prone to soil erosion. The Palouse region of northern Idaho and eastern Washington is characterized by highly erodible, deep, silt loam soils, topography that ranges from rolling hills to steep hillsides (8 – 30% slopes) (Papendick, 1996; Kok et al., 2009), and is recognized as one of the most productive, rain-fed wheat producing areas of the world (Kok et al., 2009). High rates of soil erosion across the region drove the adoption of conservation and no-till practices, which has successfully reduced soil loss from an average 45 Mg ha^{-1} yr^{-1} in the mid-1970s to approximately 11 Mg ha^{-1} yr^{-1} (Kok et al., 2009). Development of sustainable organic, no-till practices may help promote improved management, soil health and overall resiliency of agriculture in the region.

Through reduced pesticide use (Kibblewhite et al., 2008; Pelosi et al., 2013), diverse rotations (Watson et al., 2002; Anderson, 2010; Berthrong et al., 2013), and increased organic matter inputs (Shepherd et al., 2002; Fließbach et al., 2007), organic farming practices have been shown to increase indicators of soil health including soil organic carbon (SOC) content (Drinkwater et al., 1998; Fließbach et al., 2007), nitrogen (N) mineralization rates (Berthrong et al., 2013), and soil biological components that are important to nutrient cycling and soil structure (Edwards and Bohlen, 1996), such as earthworms (Pfiffner and Luka, 2007) and microbial biomass (Birkhofer et al., 2008) in rain-fed production systems. No-till practices have been shown to enhance some of these same soil health indicators due to reduced disturbance and higher crop residue retention at the soil surface (Grandy et al., 2006; Kibblewhite et al., 2008; Hansen et al., 2012). Increased soil aggregation and surface litter retention under no-till management also reduces the risk of soil erosion (Singh and Malhi, 2006; Malhi et al., 2006). Improved soil structure and SOC levels can lead to greater water retention (Grandy et al., 2006) and long-term resiliency of rain-fed systems, particularly under more variable climatic conditions (Stockdale, 2011; Palm et al., 2014).

Researchers and farmers have been investigating the integration of organic management with reduced-tillage (RT) practices since the 1990s. In Europe, ORT practices have focused on reducing the depth and frequency of non-inversion tillage (Mäder and Berner, 2012), whereas in the U.S. researchers have primarily been exploring organic, no-till practices (Carr et al., 2012). Methods used in the US have been developed primarily in sub-humid and humid regions, and use vegetative mulches and roller-crimpers for weed control and cover crop termination, respectively (Carr et al., 2013).

A recent review by Carr et al., (2013) suggests agreement in the literature that ORT and organic no-till methods have positive effects on several aspects of soil health. Compared to organic moldboard plowed soils, increases in SOC (Gadermaier et al., 2012), N availability (Drinkwater et al., 2000), and microbial biomass carbon (Berner et al., 2008; Gadermaier et al., 2012) have been observed in near-surface soil of ORT systems that received mulch till (20 -30 cm) (Drinkwater et al., 2000) or chisel plow treatments (15 cm) and occasional cultivation (< 5cm) with a rotary harrow for seed bed preparation (Berner et al., 2008; Gadermaier et al., 2012). Different indicators of soil quality, however, may not uniformly respond to ORT management. Earthworms are considered to be important biological indicators of soil health (Lee, 1995; Doran and Zeiss, 2000;

Kibblewhite et al., 2008) and their populations have been shown to increase (Peigné et al., 2009), remain the same (Berner et al., 2008), or decrease (Crittenden et al., 2014) with reduced tillage compared to plowed treatments in organic systems. Research tracking ORT impacts on soil structure has also been inconclusive. Peigné et al., (2009) observed lower bulk density and greater porosity in organic moldboard plow soils compared to three different ORT treatments after three years, despite increases in earthworm density. Overall, ORT practices appear to improve soil conditions and functions close to the surface, though our understanding is limited by the scope, study length, and geographic disparity of previous studies (Carr et al., 2013). Variation in results and the lack of studies in drier climates where roller-crimper methods have been less successful (Luna et al., 2012; Delate et al., 2012), highlight the need for further study of ORT systems.

The only ORT research of rain-fed cropping systems within dryland regions, defined as receiving < 60 cm annual precipitation (Schillinger et al., 2006), have been conducted in Montana and Washington. Decreasing the frequency of post-harvest tillage resulted in organic wheat yields that were competitive with non-organic, no-till production in silt loam textured soils in Montana (Miller et al., 2008). However, the methods used by Miller et al. still relied on intensive fall tillage, albeit infrequent, which could pose risks of soil erosion. In WA, researchers have been studying ORT cereal production systems since 2003. Gallagher et al., (2010) found that under non-inversion tillage (relying only on an undercutter, rotary harrow, and rotary hoe for tillage) alfalfa-grass and winter-pea based cropping systems produced greater amounts of biomass, provided the best weed control, and supported higher yields in successive crops than did more grain intensive ORT systems during the 3-year mandatory transition period to organic certification (USDA-NOP, 2013). Analyzing the same plots tested during the transition phase, Borrelli et al., (2012) found that alfalfa-grass and winter pea based systems provided residual inorganic soil nitrogen (N) for subsequent crops and supported higher yields during the transition and early years of production. Furthermore, winter wheat produced higher yields than spring wheat during the transition and two years that followed, though below regional conventional yields (Gallagher et al., 2010; Borrelli et al., 2012). The impacts of ORT on soil health indicators were not considered in the previous studies.

Our objective was to compare differences in soil health indicators that emerged as a result of cropping system and management in the long-term ORT plots reported on by Gallagher et al., (2010) and Borrelli et al., (2012). We analyzed soil properties related to soil health in two ORT cropping systems and one non-organic, no-till system established in 2008 as a "control". Earthworm density and biomass were measured in multiple years, and microbial biomass, aggregate stability, aggregate size distribution, hydraulic conductivity, bulk density, SOC, total nitrogen and crop yield were measured in 2013, the sixth year of the crop rotation. To our knowledge, the data reported here represent one of the first long-term, side-by-side comparisons of soil health indicators in organic vs conventional conservation tillage systems in the Palouse and greater Inland Pacific Northwest cereal production region.

2.2 Methods

2.2.1 Site description and experimental design

This study was conducted at the Boyd Research farm located in Pullman, WA (46.75° N, 117.07° W) (Gallagher et al., 2010). The climate in this region is Mediterranean with cool, moist winters, and hot, dry summers, with approximately 60% of annual precipitation occurring between November and March (McCool et al., 2001). The average annual air temperature was 8°C and average annual precipitation was 38 cm between 2008 – 2013 (Washington State University AgWeatherNet, 2013). This is slightly less than the 30-year average annual precipitation (1981-2010) of 43 cm yr^{-1}, and similar to the 30-year average temperature (8.6°C), measured from within 5 km of the research site (NOAA, 2014). The experimental plots are located on a uniform 5% southwest facing slope (Gallagher et al., 2010) and the main soil type is Palouse silt loam soil (Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls) (Soil Survey staff, 2013).

The current study is part of a longer-term cropping system trial, split into two research phases. Phase I began in 2003 with a three-year transition period required by the National Organic Program (NOP) for organic certification (USDA NOP, 2014) followed by two years of organic wheat production. Organic refers to methods that uses no synthetic fertilizers and pesticides and adhere to the standards of the NOP (USDA NOP, 2014), while conventional agricultural refers to systems that use synthetic inputs. The goal during Phase I was to compare the weed control and soil building capacity of nine ORT cropping systems (Gallegher et. al 2010; Borrelli et al. 2012). Prior to Phase I, the land had been in long-term, conventional rain-fed grain and legume production.

Phase II is the primary focus of the current study. Beginning in 2008, the original 45 plots were reallocated to 4 new cropping systems based on the findings of Phase I. At this point, 20 additional plots were put in adjacent to the original plots and allocated to two conventional cropping systems for experimental control. Plots are 9.1 x 15.2 m and located in a complete randomized block experimental design with 5 replicates (n=5). The present study focuses on 3 of the cropping systems: An organic barley, alfalfa-orchardgrass, winter wheat five-year rotation (Org-Alf-5yr); an organic spring wheat, winter pea hay, winter wheat 3-year rotation (Org-WPW); and a conventional spring wheat, winter pea hay, winter wheat 3-year rotation (Con-WPW) that is a conventional comparison to Org-WPW (Table 1). All plots were managed using reduced tillage (RT) practices, referring to non-inversion tillage practices that limit soil disturbance to within the top 5 cm of the soil.

2.2.2 Cropping systems: agronomic methods and yield

Reduced-tillage treatments were more frequent in Org-WPW and Org-Alf-5yr than in Con-WPW, representative of the different needs and practices that would be implemented under actual production circumstances. An undercutter (Haybuster Sweep), 4.5 m “double pull” Pheonix rotary harrow, and a 4.5 m M&W 15 MT (“minimum tillage”) rotary hoe with Yetter helper springs were used on all organic crop systems for weed control. Additional end of the season weed control was done with a flail mower (Haybuster, Bush Hog). All crops were seeded with a 2.2 m wide Fabro no-till drill with 19 cm wide row spacing (For more detail see Gallagher et al., 2010). The Soil Tillage Intensity Rating (STIR) developed by the National Resource Conservation Services (NRCS) to quantify the impact of machine operations on soils (USDA-NRCS, 2006) is used to compare the differences in soil disturbance among the three cropping system, described below. STIR values of less than 30 are considered to be no-till (USDA-NRCS, 2005). Minimum-till rain-fed systems may have STIR values ranging from 19 – 99, and conventional tillage can exceed 100 (Schaefer et al., 2005). STIR values for the cropping systems in this study rank according to: Con-WPW (25) < Org-Alf-5yr (36) < Org-WPW (44).

Yield values are calculated using a direct field-scale method. The middle third of each plot (3 m width strip) was harvested with a Kincaid plot combine and converted to per acre units through on-combine software (Harvest Master software, Juniper Systems, Inc., Logan, UT).

Org-Alf-5yr

In the two years prior to this study, the Org-Alf-5yr was seeded to winter barley (2007-08) and winter triticale (2008-09), receiving fall-applied manure at a rate of 410 kg N ha^{-1}in both years. Measurements for the present study began in 2010, when plots were seeded to a three-year perennial alfalfa-orchardgrass mix followed by winter wheat in 2013. Plots received no manure or other fertilizer between 2010 and 2013. Alfalfa-orchardgrass was rotary harrowed in the fall of the establishment year and first year of production, but received no fall weed control treatment in the second (final) year of production. Additional rotary hoe and mowing treatments were used for weed control as needed during the growing season of the alfalfa establishment year, and the crop was cut once for harvest. In subsequent years, three passes with a rotary hoe was used for spring weed control, generally in April and May, followed by two harvest cuttings in the production years. Post-harvest weed control with a flail mower was done in late summer or early fall in most years to impede crop and weed regrowth (Table 2.1).

Org-WPW

Org-WPW received 410 kg N ha^{-1} through manure input during the spring wheat phase in 2008 and was swathed due to high weed density. Plots were seeded to winter pea hay in 2009. Similar to Org-Alf-5yr, Org-WPW also received fall sweep and rotary harrow pre-planting treatments in all years except for the second rotation of winter pea hay (2012). Quail manure was generally applied in the fall for spring and winter wheat crops at rates between 256 and 410 kg N ha^{-1}, and was incorporated into the soil with either a rotary harrow or hoe. All crop phases of the Org-WPW system were rotary hoed between two and five times in the spring for weed control. Crops were flail mowed after harvest when weed infestations persisted. Furthermore, hay harvest in the winter pea phase, plus the option for flail mow treatments if weed pressure is high, provides supplementary weed control in this system (Table 2.1).

Con-WPW

Con-WPW followed the same crop rotation as Org-WPW in each year, with the primary differences being the use of synthetic fertilizers in place of manure, and herbicide applications in place of multiple minimum tillage treatments. Winter and spring wheat crops received 121 kg N ha^{-1} and 5 kg P ha^{-1} injected with the no-till drill. Con-WPW required less tillage than the organic plots. The undercutter and rotary harrow were not used in Con-WPW plots except in 2013 for fall weed control. The rotary hoe was used similar to Org-WPW plots in 2011 and 2012 only (Table 2.1).

2.2.3 Biological indicators: Earthworms and microbial biomass

To determine the impact of inclusion of a perennial crop on earthworm density, sampling was completed in Org-Alf-5yr annually from 2010-2013. In the Org-WPW and Con-WPW plots, earthworms were sampled during the winter wheat phases, occurring in 2010 and 2013. Earthworms were sampled in the spring (April-May) within the span of one month to minimize temperature and moisture differences between sampling days. Earthworms were hand sorted and sieved from two, hand dug pits (25 x 25 x 40 cm) in each of the 15 plots. Adult earthworms were kept alive in petri dishes with moist filter paper for 24 hours to empty their guts before live weight biomass measurements were taken. Adult earthworms were preserved in 5% formalin and identified using the key of Schwert (1990). Moisture and temperature measurements were taken at 10 cm depth intervals within each earthworm pit (Decagon GS3 Ruggedized Soil Moisture, Temperature, and EC, Pullman, WA).

Microbial biomass carbon and nitrogen were measured through a fumigation and extraction method described by Voroney et al., (2008). Five, 2-cm diameter core samples were taken from each plot to a 10 cm depth in October 2013 and stored at 4 °C in the lab before use. Soil sampling occurred after fall rains had restored soil moisture in the top 10 cm to levels suitable for microbial populations to be active. Soil was sieved (4 mm) to remove large organic matter. Paired samples (1 for fumigation, 1 for unfumigated control) of 25 g each were brought to 40% gravimetric soil moisture content and incubated at 24 °C for 48 hours. During incubation samples were stored in glass jars with small holes to allow gas exchange while maintaining constant moisture. Unfumigated samples were extracted immediately after incubation by shaking the incubated soil with 85 ml 0.5 M K_2SO_4 (1:3.4 soil:extractant ratio) for one hour, filtered, diluted 5-fold with triple distilled water, and then acidified with 36.5% concentrated HCL to between pH 2-3. Samples were acidified to remove inorganic carbon and reduce precipitation of $CaSO_4$. Fumigated samples were exposed to ethanol-free chlorophyll ($CHCl_3$) in an evacuated desiccator chamber for 24 hours and then extracted as above. Extracts were stored at -24 °C until analysis. Fumigated extractable C (FEC) and fumigated extractable N (FEN) were measured using a Shimadzu carbon analyzer (Model TOC-LCSH, Kyoto, Japan) equipped with a TNM-L nitrogen analyzer (oxidative combustion-chemiluminescence). FEC and FEN values are calculated by the difference between C and N measured in the fumigated and unfumigated samples. FEC and FEN are reported with no conversion to total microbial biomass.

2.2.4 Chemical indicators

Two replicate, 1.5 m deep soil cores were collected from each plot in May 2013 using a tractor mounted Giddings hydraulic probe (Giddings Machine Company, Windsor, CO, USA). All analyses on the duplicate samples from each plot were run individually and then averaged, with the exception of pH (see below). Soil cores were cut into six depth increments in the lab: 0 - 10, 10 – 20, 20 - 30, 30 - 60, 60 - 100, 100 - 150 cm. A representative sample of at least 25 g of soil was removed from each core segment and oven-dried for 24 hours at 105° C to measure the gravimetric soil moisture content. Gravimetric soil moisture content of the samples was used to calculate the oven dry soil mass of each corresponding core segment. Bulk density was calculated using the oven dry mass and volume of each core segment (Grossman and Reinsch, 2002).

Total organic carbon and total nitrogen (TN) for each core segment was measured by dry combustion with a CNS analyzer (Elementar VarioMax CNS; Hanau, Germany) after fine grinding (<0.25 mm) in an 8000M Mixer/Mill (PEEX Sample Prep, Metuchen, NJ). All samples from depths greater than 30 cm were tested individually with 1 M HCL for carbonates. Effervescence was observed in 3 plots in the 60-100 cm depth range, and in 6 plots at depths greater than 100 cm. All soil samples with a pH above 7.0 were acidified with 0.6 M HCL until effervescence stopped and were re-ran on the CNS analyzer to obtain total organic carbon. Thus, soil carbon data presented reflects only organic C. Soil organic carbon (SOC) stocks were calculated based on the measured soil bulk density and percent C within each core segment.

A 5-g subsample was taken from each replicate soil core segment for measurement of pH (1:1 water:soil) (Soil Survey Laboratory Staff, 2004). The pH of the poultry manure applied to the organic plots was measured from a sample taken in January 2014 (1:5 manure to water, 7 replicates) from the same manure source that had been used throughout the duration of the study. Given the controlled environment of the indoor quail facility, relatively consistent nutrient analysis from four consecutive years (mean total N= 57.2 g kg^{-1} ± 8.4 based on 7 samples; mean total Calcium=2.8 g kg^{-1} ± 0.5 based on two samples); the measurement of the 2014 manure batch is a reasonable estimate for pH.

2.2.5 Physical indicators: Aggregate stability and hydraulic conductivity

Aggregate stability and size distribution from the 0-to 10- cm depth was measured in each treatment. Sampling occurred ten days after the fall undercutter and rotary harrow treatments in Nov. 2012 and were stored at 4 °C in the lab for four days before being moist sieved (4 mm). Initial sieving was done while samples were field moist to minimize the breakdown of aggregates (Chan et al., 1994). The sieved samples were air-dried for one week, and then stored for lab analysis.

To determine aggregate size distribution, air-dried samples were dry-sieved to five size fractions (< 0.25, 0.25 - 0.5, 0.5 - 1, 1 – 2, and 2 – 4 mm) in an electromagnetic sieve shaker (Fritsch Analysette 3 PRO, Idar-Oberstein, Germany) for 5 minutes at 0.1 mm amplitude. These settings are common (Alvaro-Fuentes, 2008, 2007; Lopez, 2006) and did not cause excessive aggregate breakdown when tested in our lab. Aggregate size distribution is expressed using the mean weight diameter according to the function,

$$\mathrm{MWD} = \sum_{i=1}^{n} \overline{\mathrm{X}}_i W_i \qquad \text{Eq. 1}$$

where $\overline{\mathrm{X}}_i$ is the mean diameter of the particle size fraction, W_i is the proportion of the total sample weight that remains on each sieve, and *n* is the number of size fractions (*n*= 5) (Youker & McGuiness, 1956; Kemper & Rosenau, 1986).

Two aggregate size ranges were tested for water stability: 0.5 - 1 and 1 - 2mm. Pierson and Mulla's (1990) modified high energy moisture characteristic method developed specifically for weakly aggregated Palouse soil was used. This method reduces slaking caused by fast wetting of aggregates, however, aggregates larger than 2mm are not suitable for this method, and were thus omitted for stability measurments. Following the experimental design used by Johnson-Maynard et al. (2007), 17.5 g of soil aggregates were wet to saturation through the bottom of a sintered glass funnel connected to a hanging water column. Soil aggregates were wet at a fast (10 cm min^{-1}) and slow (2 cm min-^{1}) consistent rate using a peristaltic pump. A suction force was then applied to the aggregates by using valves to lower the height of the meniscus in the water column (burette) in 2 cm intervals. The water level was held at each interval for 2 minutes to let the system equilibrate. The mass of water outflow measured at each interval quantifies the matric potential and aggregate breakdown induced by the suction force to produce a moisture characteristic curve for the slow and fast wetting rates.

According to Collis-George and Figueroa (1984) and modifications proposed by Pierson and Mulla (1989), a stability ratio is obtained from the moisture characteristic curves by first calculating a structural index as the volume of drainable pores/modal suction.
The stability ratio is calculated by relating the fast wetting to the slow wetting structural indexes:

$$\text{Stability ratio}=\frac{\text{structural index (fast wet)}}{\text{structural index (slow wet)}} \qquad \text{Eq. 2}$$

The stability ratio of the 0.5 – 1.0 and 1 – 2 mm size aggregates for each sample can then be compared across treatments.

In May-June of 2013, field saturated hydraulic conductivity (K_{fsat}) was measured using a constant head permeameter (Guelph permeameter, Soil Moisture Equipment Corp., Santa Barbara, CA, USA). Between 3 - 5 measurements were taken in each of the 15 plots to obtain mean K_{fsat}. Measurements were taken according to the methods described by Reynolds (2008). Briefly, 15-cm deep bore holes (6 cm diameter) were dug with an auger using the ‘two finger two turns’ method to avoid compaction (Reynolds, 2008). A shaping auger was used to make the size of the bore hole uniform, and a wire brush was used to repair any smearing on the walls. Bore holes were not backfilled because no collapsing occurred. Two head measurements were taken in each hole at H1=5 cm and H2=10 cm. Use of the two-head calculation method provides better estimates of K_{fsat}

because it allows K_{fsat} and matric potential (ϕ_m) to be solved for simultaneously (Elrick et al., 1989). However, due to the presence of heterogeneity throughout the soil profile arising from horizon boundaries, earthworm burrows, roots, etc., H1 and H2 can differ substantial, subsequently producing individual K_{fsat} values that yield an overall negative and invalid K_{fsat} or matric flux potential(ϕ_m). In these instances the single head method was used, where H1 and H2 K_{fsat} values are averaged to provide a more realistic estimate (Elrick et al., 1989). K_{fsat} was calculated according to the *Guelph Permeameter Operating Instructions, 2800*, using a shape factor (C) based on soil-textural category 3 for structured agricultural soils, and α*, the microscopic capillary length factor (α*= 0.12, C=.33634) (Soil Moisture Equipment Crop., 2012).

2.2.6 Statistical analysis

All data was analyzed in SAS (Version 9.2) using PROC UNIVARIATE to test that all variables met the normality requirements for analysis of variance (ANOVA). In order to meet normality requirements for the ANOVA, earthworm biomass and density data was log transformed according to the method described by McCune & Grace (2002). This method is intended to preserve the order of magnitude within the data and keeps zero values as zero. The transformation follows:

$$b\_ij = \log(X\_ij + d) - c \qquad \text{Eq. 3}$$

where *c* is the order of magnitude constant, *c* = Int[log(Min(x))], and *d* is the decimal constant, $d = \log^{-1}(c)$. Large aggregate stability and hydraulic conductivity measurements also did not meet normality requirements and thus were transformed using a standard logarithmic calculation.

Statistical difference in soil parameters and yield were analyzed only between the Org-WPW and Con-WPW cropping systems using PROC GLM to quantify the effects on soil properties that are expected to respond to differences in organic verse conventional management in relatively short time span (< 6 years). PROC MIXED was used to quantify temporal changes in earthworm density in the four years of consecutive measurements of the Org-Alf-5yr system. Correlation between soil parameters across cropping systems were analyzed using PROC CORR, and significant Spearman Rank correlation coefficients are reported for logical comparisons. Cropping system effects and correlation coefficients are considered significantly different in this study for $p< 0.05$. Tukey's test for significant differences was used for pairwise comparisons. All average values are followed by ± standard deviation, unless otherwise noted.

2.3 Results

2.3.1 Biological indicators of soil quality

All adult earthworms collected between 2010-2013 were identified as *Apporectodea trapezoides*. Statistical analysis of log-transformed data suggests a significant cropping system main effect ($p=0.009$) on earthworm density between Org-WPW and Con-WPW. Year was significant ($p<0.001$), but cropping system*year interaction was non-significant ($p=0.28$); therefore earthworm density was averaged across years (Fig. 2.1a). Org-WPW average earthworm density (109 individuals m^{-2}, ± 95) was approximately double that measured in Con-WPW (51 individuals m^{-2}, ± 40). Earthworm density increased by a factor of 6.0 in Org-WPW and by a factor of 3.1 in Con-WPW over four years (data not shown). Earthworm biomass ($p=0.096$) was not significantly different between the three year cropping systems due to large variation within the data. Average earthworm biomass was 52.1 g m^{-2} (± 47) in Org-WPW and 24.8 g m^{-2} (± 16) in Con-WPW (Fig. 2.1b).

Average earthworm density in Org-Alf-5yr increased by a factor of 2.8 from 2010 to 2013 ($p=0.001$) (Fig. 2.2a). While not compared statistically, Org-Alf-5yr had earthworm density (187 m^{-2}, ± 153) and biomass values (62.2 g m^{-2}, ± 42.5) similar to those measured in the Org-WPW cropping system in 2013 (data not shown). Earthworm density did show a significant increase until 2013, after the three years of perennial alfalfa-grass had been terminated and plots were seeded into winter wheat (Fig. 2a).

Earthworm biomass in Org-Alf-5yr did not differ across years, and ranged from 30.0 g m^{-2} (±45.3) to 62.2 g m^{-2} (±11.1) (p=0.283)(Fig. 2.2b).

Soil temperature and moisture content measured within the earthworm pits did not vary significantly between cropping systems at the time of sampling. Average soil temperature from the 0–to 40-cm depth measured in earthworm pits during the 2013 sampling ranked in the following order: Org-Alf-5yr (8.7° C, ±2.0) < Org-WPW (9.0° C, ±2.5) < Con-WPW (9.7° C, ±3.2). Soil moisture content averaged across all cropping systems in the top 40 cm of soil was 0.36 m^3 m^{-3} (±0.03), with the average soil moisture ranging from 0.36 m^3 m^{-3} (±0.03) in the 0–to 10-cm depth to 0.34 m^3 m^{-3} (±0.07) in the 30–to 40-cm depth.

Fumigated extractable C measurements suggest a strong trend of greater microbial biomass C in Org-WPW compared to Con-WPW (p=0.058), while no difference in FEN was observed between Org-WPW and Con-WPW (p=0.154). Fumigated extractable C was 26% greater in Org-WPW (100.3 µg g^{-1}, ±11.8) than in Con-WPW (76.9 µg g^{-1}, ±8.4) (Fig. 2.3a). Mean FEC within Org-Alf-5yr was 108.8 µg g^{-1} (±24.6), similar to that measured in Org-WPW. Fumigated extractable N in all three cropping systems was similar and ranged from 7.0 µg g^{-1} (±2.5) in Con-WPW to13.4 µg g^{-1} (±1.7) in Org-Alf-5yr (Fig. 2.3b).

2.3.2 Chemical indicators

Soil pH, SOC and to a lesser extent total N, differed between cropping systems after six years of production, with the greatest divergence within the shallowest depths. Of these properties, cropping system had a significant main effect on soil pH only (p=0.005), though depth by cropping system interactions for pH were only significant within the first 30 cm (p<0.05) (Fig. 2.4). Average soil pH within the 0–to 10-cm (5.7 ±0.23) and 10–to 20-cm (5.7 ±0.17) depths in Org-WPW was greater than in the same depths (0-10 cm= 5.3 (±0.27) and 10-20 cm= 5.4 (±0.13)) under Con-WPW. Within the 20–to 30-cm depth, soil pH was 6.2 (±0.18) in Org-WPW and 5.8 (±0.12) in Con-WPW. Soil pH in Org-

Alf-5yr ranged from 5.6 (±0.13) within the 0-to 10-cm depth, to 7.1 (±0.34) in the 100– to 140-cm depth (data not shown). Soil pH in Org-Alf-5yr and Org-WPW were similar at all depths except in the 100 – 140 cm range where pH was greater in Org-Alf-5yr. The poultry manure that was used in the organic systems had a pH of 7.4 (±0.06).

While cropping system did not significantly impact cumulative SOC and total N stocks for the full soil profile (SOC, p=0.763; total N, p=0.655) (Fig. 2.5a), significant depth by cropping system interactions show a stratified distribution by depth for SOC Mg ha^{-1} (p=0.012) and to a lesser extent for total N Mg ha^{-1} (p=0.063) (Fig. 2.5b). SOC in the 0-to 10-cm depth within Org-WPW (28.6 Mg ha^{-1}) was significantly greater (p=0.014) than Con-WPW (23.5 Mg ha^{-1}). Approximately 50% of the total SOC stock was found within the top 30 cm of soil in each of the three cropping systems. Cropping system has less of an effect on total N stocks within the 0-to 10-cm depth where total N ranged from 1.6 Mg ha^{-1} in Con-WPW to 2.0 Mg ha^{-1} in Org-WPW and Org-Alf-5yr (Fig. 2.6). While there was a trend of greater total N stock in Org-WPW compared to Con-WPW in the top 10 cm (p=0.080), measurement by percent total N indicated significantly higher levels in Org-WPW (0.13%) than Con-WPW (0.11%) (p=0.010).

2.3.3 Physical indicators

Differences in cropping system had little impact on soil physical properties after 10 years of ORT crop rotations. Results of soil physical property measurements did not correspond to differences in soil disturbance among cropping systems (STIR values). Aggregate stability ratios were similar in the Org-WPW and Con-WPW for both the small (0.5 – 1.0 mm, p=0.285) and large (1 – 2 mm, p=0.272) aggregate size ranges (Fig. 2.7). However, the cropping systems ranked in the same order by stability ratio for both aggregate size ranges, from least to greatest: Con-WPW < Org-WPW < Org-Alf-5yr. The stability ratio of small aggregates (0.49 for Org-Alf-5yr and 0.33 for Con-WPW) was greater than that measured for larger aggregates (0.43 for Org-Alf-5yr and 0.31 for Con-WPW). In Org-WPW, however, the stability ratios of aggregates of both size fractions were nearly equal (small=0.37, large=0.38). The MWD of dry aggregates sieved to less than 4mm was consistent across all three cropping systems: Con-WPW = 1.87 mm, Org-Alf-5yr = 1.89 mm, and Org-WPW= 1.96 mm. For all three cropping systems, less than 10% of soil aggregates sieved to 4mm were smaller than 0.5 mm diameter and larger aggregates were most abundant. Aggregates within 0.5 – 1 mm accounted for 20%, 1 – 2 mm aggregates accounted for 35%, and 2 – 4 mm aggregates accounted for 41% of total sieved soil.

Field measured saturated hydraulic conductivity (K_{fsat}) showed a high level of variability among replicate plots. Mean K_{fsat} (cm day^{-1}) in Org-WPW and Con-WPW was not statistically significant (p=0.840). Values for each system ranged from 12.4 (± 9.7) in Org-Alf-5yr to 13.8 (± 10.4) in Con-WPW (data not shown).

No significant differences in bulk density between Org-WPW and Con-WPW cropping systems were observed (p=0.856). In the top 10 cm of soil within all three cropping systems, bulk density measurements were similar, ranking from least to greatest according to Org-Alf-5yr (1.40 g cm^{-3}) < Con-WPW (1.42 g cm^{-3}) < Org-WPW (1.45 g cm^{-3}). Bulk density atypically decreased with depth in the 0-to 30-cm range, whereas at depths >30 cm there was a gradual increase with depth up to 140 cm (Fig. 2.8).

2.3.4 Yield

Org-WPW and Con-WPW produced similar yields throughout all crop years included in this study, with the exception of the winter pea hay. Winter wheat yields in Org-WPW (5.4 Mg ha^{-1}) and Con-WPW (4.0 Mg ha^{-1}) were similar in 2010 (p=0.100), as were 2011 spring wheat yields for Org-WPW (2.6 Mg ha^{-1}, ±0.48) and Con-WPW (2.8 Mg ha^{-1}, ±0.51) (p=0.397). Winter pea hay yields in 2012 were higher (p=0.004) for Org-WPW (3.5 Mg ha^{-1}) than Con-WPW (0.7 Mg ha^{-1}) due to a killing frost in early spring that affected the conventional crop more than the organic, likely because greater weed cover in Org-WPW shielded the crop from the frost. In 2013, all three cropping systems were in the winter wheat phase of rotation. Org-WPW (5.3 Mg ha^{-1}, ±0.55) and Con-WPW (4.6 Mg ha^{-1}, ±1.39) yields were similar (p=0.340) and both significantly greater than those measured in Org-Alf-5yr (2.1 Mg ha^{-1} ±0.53) ($p<0.002$). After six years of crop production, Org-WPW and Con-WPW winter wheat yields were not significantly different, however both were significantly greater than in Org-Alf-5yr. (See Fig. 2.9)

2.3.5 Correlation of soil parameters

Significant correlations among soil quality indicators occurred within the 0-to 10-cm depth. Earthworm density and SOC Mg ha^{-1} ($r=0.71$, $p=0.003$) and earthworm density and total N Mg ha^{-1} ($r=0.71$, $p=0.003$) were significantly, positively correlated. Earthworm biomass and FEN ($r=0.53$, $p=0.045$), and earthworm density and FEC ($r=0.58$, $p=0.023$) were also significantly correlated. The only significant correlation between chemical and physical indicators of soil quality was between SOC (on a percentage basis) and the stability of large soil aggregates ($r=0.56$, $p=0.030$) (Fig. 2.10 & 2.11).

2.4 Discussion

2.4.1 Biological indicators

Earthworms

The fact that only one species of earthworm was found at this site was not entirely surprising and is consistent with results of past studies and the sampling methodology used. *A. trapezoides* has been reported as being dominant in agricultural soils within the region (Fauci and Bezdicek, 2002; Johnson-Maynard et al., 2007; Umiker et al., 2009). While *A. trapezoides* is clearly a common earthworm in the Palouse region, it also may be favored by the most common sampling technique (handsorting) used in this study and those cited in the literature. Bouche (1977) originally defined earthworm species into three functional groups: anecic species are surface feeders that create deep vertical burrows; endogenic species create horizontal burrows generally in the upper soil horizons, feeding primarily on organic matter within in the profile; and epigeic species that dwell and feed at the soil surface (Lee, 1995). We may not have found anecic species because our handsorting method is not considered to be optimal for sampling deeper burrowing species (Callaham Jr. and Hendrix, 1997). While we cannot definitively state that anecic species are absent from our site, the surface disturbance caused by field operations (Table 1) may have been sufficient to prevent their proliferation (Ernst and Emmerling, 2009).

Our results are in agreement with other studies that indicate organic production practices can have positive impacts on soil biological communities (Carpenter-Boggs et al., 2000; Mäder et al., 2002; van Diepeningen et al., 2006; Birkhofer et al., 2008; Stockdale and Watson, 2009). Significantly greater earthworm density in Org-WPW compared to Con-WPW may be due to a number of factors including differences in disturbance, food availability and pesticide use.

The effect of tillage on earthworm abundance can be both positive or negative depending on soil conditions, the type and intensity of the tillage, and differences in behavioral needs of species functional groups (Chan, 2001). Greater earthworm density in Org-WPW than Con-WPW, despite greater disturbance in Org-WPW (STIR=44) compared to Con-WPW (STIR=25), is likely a result of the soil disturbance being limited to shallow depths (5cm) and the behavioral characteristics of the dominant endogeic species. No-till practices often promote earthworm density in conventional agricultural soils (Chan, 2001; Castellanos-Navarrete et al., 2012); specifically, *A. trapezoides* has been observed to increase under no-till management in conventionally managed Palouse soils (Johnson-Maynard et al., 2007). However, incorporating organic matter into the soil profile with inversion tillage (plowing to 25 cm depth) can also increase the abundance of endogeic species relative to reduced-tillage treatments (Ernst and Emmerling, 2009). The tillage in the current study did not breach the entire depth of *A. trapezoides'* typical habitat, which for endogeic species is usually the A_1 horizon (Lavelle, 1997) (A_1 = approximately 0 – 15 cm at this site). The tillage practices in our study may have incorporated sufficient organic matter from manure and crop residues (i.e. easily accessible food resources) while also minimizing habitat disturbance, thus benefiting the endogeic-dominated earthworm population.

Studies that compare the impact of different tillage methods on endogeic species in organic systems report mixed results. Eliminating inversion tillage in organic cropping systems can have no impact on endogeic species abundance (Peigné et al., 2009), reduce abundance (Crittenden et al., 2014), or increase the abundance (Berner et al., 2008). Our results were in line with that of Berner et al. (2008) who observed no change in total earthworm abundance, but 70% more endogeic species under reduced-tillage (rotary harrow to 5cm and chisel plow in one of three years) compared to moldboard plowed treatments after three years. The land had been under organic management for seven years before the tillage treatments began, which may have contributed to the lack of change in total abundance. By contrast, Crittenden et al., (2014) reported mean endogeic earthworm abundance to be 45% lower under minimum and non-inversion tillage compared to moldboard plow treatments after 4 years, and that endogeic species abundance was negatively correlated to soil compaction that occurred under reduced-tillage. However, earthworm populations were higher under reduced-tillage than plowed treatments when sampled during grass-clover phases of rotations that left greater amounts of plant matter on the soil surface (Crittenden et al., 2014).

Some of these differences in tillage effects on earthworm populations may be related to food supply, and may explain the greater earthworm density we observed in Org-WPW than Con-WPW despite greater tillage in Org-WPW. Org-WPW received between 4.5 - 7.2 Mg ha^{-1} yr^{-1} of manure during wheat phases (3 of 4 years) (Table 2.1), and may have benefited from a more robust winter pea hay crop than in Con-WPW (See yields in Fig. 2.9a). Greater earthworm density under organic management as compared to conventionally managed cropping systems is often attributed to greater abundance of food sources (organic matter), supplied through manure fertilizers (Marinissen, 1992; Pfiffner and Mäder, 1997; Pfiffner and Luka, 2007; Birkhofer et al., 2008). In low-input (non-organic) cropping systems, Schmidt et al. (2003) observed that a continuous and plentiful food supply provided by a clover intercrop benefits earthworm populations more than the effect of eliminating inversion tillage by switching to direct-seeding. After these management changes were made, earthworm populations increased more so under wheat direct-seeded into the clover cover crop than in direct-seeded wheat with no cover crop (Schmidt et al. 2003). The findings were attributed to a larger and more continuous food supply (organic matter) in the wheat-clover system (Schmidt et al., 2003).

Our findings support that of Schmidt et al. in so far as consistent food availability appears to be a stronger factor in earthworm population size than reducing soil disturbance regimes. This theory is also supported by the observations of Crittenden et al. (2014), that earthworms may be more capable of adapting to compaction when additional, plentiful food sources are available, and by similar earthworm densities in Org-WPW and Org-Alf-5yr in 2013, measured six months after autumn tillage occurred to remove alfalfa in Org-Alf-5yr. Many have observed an initial decline in earthworm numbers due to a tillage event, followed by full recovery of the population within 6 months to a year (Marinissen, 1992; Chan, 2001; Crittenden et al., 2014), particularly when the tillage resulted in large amounts of plant material being incorporated into the soil (Chan, 2001). Mixing of plant matter into the soil surface with the rotary harrow after three years of perennial alfalfa appeared to benefit earthworm populations similarly to the manure inputs applied to Org-WPW. Peigné et al., (2009) observed a similar trend of low to steady earthworm abundance under organic lay-crop phases, followed by notable increase in population size after tillage to terminate the ley phase. The results from our study and others mentioned here suggest that earthworms in soils with higher organic matter inputs may be more resilient to soil disturbances.

While we observed significant differences in earthworm density between cropping systems, biomass measurements were not statistically different due to large variation within the data (Fig. 1b). The fact that we collected many small, juveniles during our early spring sampling likely also contributed to the lack of significant differences in biomass values. Berner et al. (2008) reported a significant decrease in the biomass of endogeic earthworms in a study of ORT cropping systems, despite an increase in density. The conflicting impact of ORT on density and biomass was related to a decrease of food availability in the reduced tillage treatments. In our study there was a non-significant trend for increased biomass (p=0.096) suggesting that food quality and quantity may not have been an issue.

The absence of chemical herbicide treatments in the organic cropping systems may also be a reason for increased earthworm populations (Reganold et al., 1993). The extent that earthworms are affected by pesticides depends on the frequency of application, species of earthworm, and type of pesticide, with insecticides being more harmful than herbicides and fungicides (Pelosi et al., 2013). Pesticide applications were limited to herbicides only in our study, and were applied one time per year (in spring) to the Con-WPW plots. However, herbicides can reduce earthworm food supply by diminishing overall organic matter input (Pfiffner and Luka, 2007). Endogeic species that have less contact with the soil surface than species of other functional groups tend to be impacted by pesticides to a lesser extent (Edwards and Bohlen, 1996; Pelosi et al., 2013), though a field experiment found that reduced pesticide use increased earthworm density of endogeic, epigeic and anecic species (Pelosi et al., 2013). By contrast, a review of pesticide effects on soil invertebrates reported no effect of herbicides on Lumbricidae (earthworms) (Jänsch et al., 2006). Herbicide application likely had minimal direct effect, and potentially only a marginal indirect effect, on earthworm density in the Con-WPW system.

Microbial Biomass

The trend of greater FEC in the organic systems (Org-WPW and Org-Alf-5yr) compared to the conventional system (Con-WPW) is in accordance with that reported in the literature (Gunapala and Scow, 1998; van Diepeningen et al., 2006; Kramer et al., 2006; Marinari et al., 2006; Fließbach et al., 2007), though our results indicate smaller differences between organic and non-organic management than those previously reported. In the current study, more frequent disturbance in the Org-WPW (STIR=44) than in Con-WPW (STIR=25) may have lessened the increase in microbial biomass relative to that reported in other studies where tillage is held equal. Microbial biomass C has been shown to increase with reduced-tillage in other Palouse soils, though the increase is often restricted to 0- 5 cm of the soil surface (Purakayastha et al., 2009). Soil type can have a larger impact on microbial biomass than cropping system (van Diepeningen et al., 2006), though in the present study this is unlikely because the plots were distributed across a slope of uniform soil type.

The trend of greater FEC in Org-WPW compared to Con-WPW is likely related to properties of the fertilizer inputs. Microbial biomass responds to increased organic matter (Stark et al., 2008). Short term application (3 years) of manure fertilizer can cause an increase in microbial biomass compared to the effect of mineral NH_4-NO_3 fertilizer (Rochette and Gregorich, 1998), and this same trend is maintained in the long-term (21 years) (Fließbach et al., 2007). To a lesser extent than organic fertilizers, mineral fertilizers may increase microbial activity by stimulating decomposition of existing soil organic matter (Marinari et al., 2000). Furthermore, microbial activity is dependent on more than just manure fertilizer, as the overall farming system (mineral fertilizer plus pesticide use) can lower soil microbial biomass (Fließbach et al., 2007).

FEC is similar in the organic treatments of the current study, despite the fact that Org-WPW received approximately 19 Mg ha^{-1} of manure over the four-year-period prior to soil sampling, while Org-Alf-5yr received no manure during this time. However, Org-Alf-5yr did receive 14 Mg ha^{-1} manure between 2008 and 2009 (in the 2 years prior to our measurements). Microbial biomass may exhibit short-term (within a growing season) increases following the application of plant-based (Stark et al., 2007) and manure-based (Rochette and Gregorich, 1998) organic amendments, and may remain elevated for a number of years (2 or more) after the addition occurs (McGill et al., 1986; Rochette and Gregorich, 1998). Furthermore, McGill et al. (1986) showed that organic matter from plant roots of a terminated forage crop can have significant impacts on microbial biomass in the subsequent year, and that microbial biomass C is more dependent on long-term C inputs than short-term additions. Others have observed short-term increases in microbial biomass after additions of leguminous plant material (Lupin) (Stark et al., 2007). Thus, the cumulative 14 Mg ha^{-1} of manure that the Org-Alf-5yr system received in 2008 – 2009 (six years prior to sampling), followed by organic matter inputs from the perennial alfalfa crop residue for three years, likely had a residual cumulative effect on increasing microbial populations. Additionally, lower disturbance in Org-Alf-5yr relative to that in Org-WPW may have increased microbial biomass C in Org-Alf-5yr. The combination these management strategies in the Org-Alf-5yr system appeared to enable similar FEC levels to that in the Org-WPW system, which received more recent, greater quantities of manure fertilizer.

The lack of difference between FEN in Org-WPW and Con-WPW is a divergence from trends cited in the literature (Gunapala and Scow, 1998; van Diepeningen et al., 2006; Kramer et al., 2006; Marinari et al., 2006; Fließbach et al., 2007). However, microbial biomass N can have a weaker response to organic matter inputs than microbial biomass C (Santos et al., 2012). Furthermore, earthworms release nutrients from microbial biomass through quickening the turnover rate of microbial populations, which can lead to decreased microbial biomass N and increased mineralized N (Edwards et al., 1995). This may be a reason that we observed a stronger, higher trend of total N in cropping systems with greater earthworm density (r=0.71), while seeing a weaker positive relationship between earthworm biomass and FEN (r=0.51) (Fig. 2.10). While not statistically compared, the apparent trend of greater FEN in Org-Alf-5yr compared to Org-WPW may have been due to microbial immobilization of N derived from the alfalfa crop. Harris and Hesterman (1990) reported that SOM contained greater than 90% alfalfa biomass-derived N, 16-19% of which was within the microbial biomass portion of SOM, measured after corn harvest following alfalfa. Additionally, alfalfa shoots made up a greater amount of N contributions than roots in this study. Though the alfalfa crop in the Org-Alf-5yr system was harvested for hay in all years three years, mowing of the crop before and after hay harvest for weed control would result in the return of some portion of the above ground biomass to the soil, which may have contributed to higher FEN.

2.4.2 Chemical indicators

Increases in bulk soil SOC and total N in the current study mirrored that of FEC and FEN. The organic C pool (including both SOC and FEC) appeared to be more responsive to organic than conventional management than did total N and FEN. In the Org-WPW system, we observed higher SOC stocks, FEC and a trend of higher total N in the top 10 cm of soil, compared to Con-WPW, however, no differences were observed below this depth. Greater addition of organic matter through manure compared to mineral fertilizers is one likely contributor to the increases in the organic system (Clark et al., 1998; Drinkwater et al., 1998; Pulleman et al., 2003; Kramer et al., 2006; Birkhofer et al., 2008). Greater organic inputs appear to have balanced enhanced mineralization rates that may have occurred due to the greater disturbance under Org-WPW. It is suggested that increased disturbance (tillage) (Peigné et al., 2007) and additions of easily decomposable C sources (manure) can lead to accelerated mineralization of SOM (Blagodatskaya and Kuzyakov, 2008). Consequently, these conditions can prohibit SOC accumulation in some organic systems (Marinari et al., 2006). Berner et al. (2008) observed SOC accumulation (7.4% after 3 years) in ORT systems compared to moldboard plowed organic systems where SOC levels remained consistent. This was attributed to slower decomposition of plant matter and manure inputs in the reduced-tillage treatments, where the soil was less aerated than under moldboard plow treatments (Berner et al., 2008). The benefit of reducing tillage in organic farm systems on SOC was summarized in a recent review of ORT systems, reporting an average of 1.1 g C kg^{-1} greater SOC in 0 – 30 cm of ORT soil compared to organically managed soils under conventional tillage (Carr et al., 2013).

Coinciding with increases in SOC, greater soil N and microbial biomass N are often observed in organic soils compared to conventional (Marinari et al., 2000; Pimentel et al., 2005; Marriott and Wander, 2006). By contrast, we observed similar levels of FEN and total N in the organic and conventional systems in the spring of 2013 despite higher total N input to Org-WPW (256 kg N ha^{-1},) than Con-WPW (121 kg N ha^{-1}) in fall 2012. Additionally, both crops likely received some amount of residual soil N from the preceding winter pea crop, which left an average of 188 kg inorganic N ha^{-1} soil when grown as a green manure crop during Phase I (Borrelli et al., 2012). Inputs in our study may be significantly lower than this value due to the biomass removed for hay under Phase II crop rotations. Compared to soils managed conventionally, organic soils can have greater N mineralization rates (Pulleman et al., 2003; Berthrong et al., 2013), and greater N retention, as a result of microbial response to organic C inputs and differences between the microbial community structures (Berthrong et al., 2013).

Some of the additional N added to the Org-WPW system through manure may have been lost due to leaching over winter months, despite research suggesting organic soils can have a higher capacity to retain N (Pimentel et al., 2005). We did not observe any accumulation of total N with depth (up to 140 cm), suggesting that N was either taken up by plants or leached beyond the measured soil profile depth. Loss of nitrogen through volatilization of NH_4^+ to $NH_{3\ (g)}$ may have been stimulated under aerated conditions following shallow-tillage in the fall or early spring. Loss of nitrate (NO_3^-) through denitrification can increase relative to leaching in soils amended with manure due to changes in the microbial population, resulting in increased emission of N_2 gas compared to the N_2O, a more harmful greenhouse gas (Kramer et al., 2006). Although, nitrogen exports from the systems were not measured, high protein content in organic winter wheat grain (Org-WPW=12.3 % compared to 10.5% in Con-WPW in 2010) and yields near those of the conventional system suggest adequate to high levels of N uptake by crop plants and potentially minimal losses via other mechanisms. Further research of the N dynamics would be necessary to better understand the flux pathways. Additionally, the manure application rate was high in this study. Future research of similar ORT systems with lower N inputs than that applied here are suggested to determine if similar yields would be attainable under such conditions. This could improve efficiency, potentially reducing N losses, and lower protein levels for soft white winter wheat crops to the optimal range of 10% (Wysocki et al., 2005).

During transition to organic certification (Phase I), prior to the time period for this study, N-fixation in alfalfa-grass stands combined with biomass removal as forage resulted in a slight gain in plant available N, determined by the N-balance after three years (41 kg inorganic N ha^{-1}) (Borrelli et al., 2012). Nitrogen uptake and removal for hay harvest nearly equaled the return from crop above-ground biomass throughout the three years of perennial alfalfa, though root N was not included in this study. Nitrogen-fixation during the alfalfa ley phase could also be a source of some soil N accumulation in the Org-Alf-5yr. Legume derived N inputs vary greatly, but average N fixation by legume crops is approximately 20 kg shoot N per ton of shoot dry matter (Peoples et al., 2009). Furthermore, mineralization of legume derived N can be slow, releasing increasingly smaller quantities to subsequent crops with time, on average <5 - 10% per year (Peoples et al., 2009). Thus continuous alfalfa-grass crops could lead to an accumulation of soil N. Also, as mentioned above (Microbial biomass section), a residual effect of the manure applied to Org-Alf-5yr prior to the alfalfa-phase may partially explain the similar total soil N levels in Org-WPW and Org-Alf-5yr.

Soil pH in the 0-to 10-cm depth was significantly lower under Con-WPW than in the same depth under Org-WPW. While not statistically compared, pH within the Org-Alf-5yr system (5.6) was very similar to that measured in the Org-WPW system (5.7, 0-to 10-cm depth). Major differences between the organic and conventional systems studied include the use of organic fertilizers versus mineral fertilizers. Greater organic matter inputs to the Org-WPW system from the poultry manure could buffer pH (Wortman et al., 2011). Aluminum complexation and increased base saturation are mechanisms by which greater organic matter inputs from manure fertilizer can have a pH buffering effect (Shiralipour et al., 1992; Wortman et al., 2011). Poultry manure inputs increased the exchangeable pool of calcium (Ca) and magnesium (Mg) and soil pH after 8 years (Clark et al., 1998). Similarly, Wortman et al. (2011) reported increased Ca, Mg, and pH in organically managed soils amended with semi-composted bovine manure, suggesting that calcium carbonate in animal manures provides a liming effect. The poultry manure used in the current study was slightly to moderately alkaline (pH 7.4), and elemental Ca content averaged 4.7%, equating to approximately 210 kg Ca ha^{-1} applied in fall 2012, and is thus a likely contributor to higher pH in the organic systems in this study. Higher pH in the organic systems of the present study is in agreement with the findings of several other studies comparing organic and conventionally managed soils (Reganold et al., 1993; Clark et al., 1998; Mäder et al., 2002; Birkhofer et al., 2008; Wortman et al., 2011).

2.4.3 Physical indicators

We did not observe substantial differences in the physical properties we considered between cropping systems, despite changes to biological and chemical properties. Pulleman et al. (2003) reported that increases in SOM, earthworm activity and water-stable macroaggregation in organic soils did not result in measurable improvements to overall soil structure. The lack of observable soil structural improvements may be partially explained by the Palouse silt loam soils being characteristically weakly aggregated (Pierson and Mulla, 1989) and the relatively short management history of the current study. In nearby conventionally managed Palouse silt loam soils, three years of no-till did not result in significant changes in bulk density, saturated hydraulic conductivity or stability of aggregates between 0.5 – 1 mm, despite a significant increase in earthworm density (Johnson-Maynard et al., 2007). Similarly, after three years of reduced tillage in organic systems, Peigné et al. (2009) reported lower porosity and higher bulk density compared to organic moldboard plowed soils. They suggested a longer-time period is required to observe soil structural changes due to soil biological factors. Studies that report soil structural differences due to differences in agricultural methods made observations after >40 years of conventional and organic management had been in place (Reganold, 1988; Gerhardt, 1997).

Temporal changes in aggregate stability may have also impacted our results. Aggregate stability samples were taken one week after autumn rotary harrow treatment and following fall precipitation, which may have temporally reduced stability differences. In previous research in Palouse soils, greater aggregate stability was found in 0.5 – 1 mm aggregates of long-term organically managed soils compared to conventionally managed soils when sampled in the autumn, however, no difference in stability was observed between the two systems during temporal freeze thaw cycles, at the beginning of soil cohesion periods, and following soil disruptions (Pierson and Mulla, 1989). To account for these variations, multiple measurements throughout the year may be necessary to detect differences between management systems.

2.4.4 Correlation of soil parameters

The Spearman rank correlation test of all measured soil properties produced five paired soil parameters with significant correlation coefficients, four of which included earthworm properties (Fig. 2.10 and 2.11). The relation between earthworm density and SOC content that we observed is well documented (Berner et al., 2008; Birkhofer et al., 2008; Ernst and Emmerling, 2009; Umiker et al., 2009; Crittenden et al., 2014), as greater food sources will support larger earthworm populations (Edwards and Bohlen, 1996). Endogeic earthworms may feed both on surface plant litter and organic matter within the soil, incorporating organic matter into the soil profile and accelerating decomposition (Edwards and Bohlen, 1996), thereby increasing SOC within the profile (Edwards et al., 1995). By increasing organic matter decomposition, earthworms also facilitate the cycling of N contained in these materials (Blouin et al., 2013), which supports the positive association to greater N stock we observed. In temperate cultivated soils, the flux of N through earthworm biomass can range from 10 – 74 kg ha^{-1} annually (Whalen and Parmelee, 2000; Blouin et al., 2013). The correlation we observed between earthworm density and total N suggests potentially enhanced N cycling as observed by Whalen and Parmelee (2000) for *Aporrectodea spp*. and *Lumbricus spp*., however, this theory is contingent upon N cycling enhanced by earthworm activity also coinciding with higher total N retention within the soil. Furthermore, visual assessment of grouping by cropping system in Fig. 10b suggests a trend of greater earthworm density and total N in the systems that received manure fertilizers. Others have also reported trends of greater N flux through earthworm populations in soils that receive manure verses mineral fertilizers (Whalen and Parmelee, 2000; Blouin et al., 2013).

Positive correlation of earthworm density to FEC and earthworm biomass to FEN suggests the impact of the availability of mutual food source for both soil organisms. Increases in earthworm populations are commonly associated with increases in microbial biomass (Curry and Schmidt, 2007; Birkhofer et al., 2008). The food supply for earthworms and microbial populations are intimately related. Earthworms increase the availability of food sources to micro-organisms through shredding and fragmenting plant material (Edwards and Bohlen, 1996), while micro-organisms decompose plant litter to more easily digestible forms for earthworms (Curry and Schmidt, 2007). For instance, microbial biomass enriched with labile carbon was greater in soil surrounding earthworm burrows and in casts of *Lumbricus terrestris* than in bulk soil (Bohlen et al., 2002), supporting the positive correlation between earthworms and microbial biomass carbon (FEC) that we observed. Direct predation of earthworms on microorganisms does occur, though it varies between species of both soil organisms. Microorganism populations are stimulated in the gut of earthworms and in casts and burrows that are enriched with carbon and high protein mucus that can accelerate the mineralization of plant available forms of N and phosphorous (P) (Brown and Doube, 2004). Earthworm casts are thus rich sources for microbial nitrification and denitrification, and the drilosphere (soil surrounding earthworm burrow walls) can support elevated populations of autotrophic nitrifying bacteria (Blouin et al., 2013). Rapid decomposition of N derived from earthworm tissue and incorporation into the microbial biomass (Whalen et al., 1999) also supports the positive correlation between earthworm biomass and FEN that we observed (Fig. 2.10d).

The positive correlation between aggregate stability of large (1 – 2mm) aggregates and % SOC is largely supported by evidence showing that organic matter plays an important role in water-stable macroaggregates (>0.25 mm) (Tisdall and Oades, 1982; Pierson and Mulla, 1990; Chenu et al., 2000). Similar to our results, Ketterings et al. (1997) reported greater C content in water stable aggregates >1 mm, though this relationship has not been observed for aggregates in the 0.25 – 1 mm diameter range (Pierson and Mulla, 1989; Ketterings et al., 1997). Water-stable microaggregates result from permanent organo-mineral binding agents, and water-stabile macroaggregates depend on the fluctuation of organic C content, roots and fungal hyphae that are influenced by agricultural management (i.e. tillage) (Tisdall and Oades, 1982). Labile forms of soil organic matter and microbial biomass C play an important role in aggregate stability, particularly in early stages of formation (Cheng-Liang et al., 2012). Microbial cells and excretions have been shown to increase aggregate stability in Palouse silt loam soils, specifically (Lynch and Elliott, 1983), and Elmholt et al. (2008) has indicated the significance of fungal hyphae bonding mechanisms and carbohydrate-C binding mechanisms in the formation of different sized aggregates. The positive correlation between SOC and aggregates stability that we observed suggest that agricultural management practices in this study that support higher SOC may also improve aggregates stability given a longer time period (Fig. 2.11).

2.4.5 Yield

Other studies report increases in organic rain-fed crop yields (Entz et al., 2001; Pimentel et al., 2005; Wortman et al., 2011), including organic, reduced-tillage systems (Miller et al., 2008). In the current study, crop yields in the organic three-year rotation were similar to that of the conventional three-year rotation. Boyd organic and conventional winter wheat yields averaged for 2010 and 2013 were lower than typical conventional winter wheat yields for the high precipitation zone of the Palouse: 4.3 Mg ha^{-1} (± 1.13) for Boyd conventional, 5.4 Mg ha^{-1} (± 0.84) for Boyd organic, compared to 6.1 – 6.9 Mg ha^{-1} regional (Schillinger et al., 2003). Thus, organic winter wheat yields in our study are about 11% less than the low end of regional yields, whereas (Birkhofer et al., 2008) reported a 20% decrease in organic winter wheat compared to conventional. A cropping system trial in Bozeman, Montana reported ORT winter wheat yields similar to a conventional no-till comparison, following a similar crop rotation to the Boyd systems (Miller et al., 2008). Berner et al. (2008) indicated an increase in ORT yields with time during the transition to reduced tillage, but that ORT grain yields in the third year were still 8% less than yields in the traditional ploughed organic system. The results of the current study and other ORT studies suggest that with time, yields of ORT crop systems can be competitive with conventional no-till systems.

In 2013, we observed lower winter wheat yields following alfalfa in Org-Alf-5yr compared to winter wheat yields following winter pea in Org-WPW. This was at least partially due to poor termination of alfalfa in the preceding year, leaving substantial amounts of the three-year alfalfa stand to compete with the 2013 winter wheat crop.

Thus, yields would likely have been higher if the alfalfa stand had been removed more uniformly.

Boyd spring wheat yields (2.8 Mg ha^{-1} ±0.51 for conventional; 2.6 Mg ha^{-1}, ±0.48 for organic) were also less than the regional conventional average, ranging between 4.0 – 6.1 Mg ha^{-1} (Schillinger et al., 2003). Several studies report lower yields in organic compared to conventional cropping systems (Birkhofer et al., 2008; de Ponti et al., 2012), including earlier studies from the Boyd cropping system plots (Gallagher et al., 2010; Borrelli et al., 2012). No regional comparisons for conventional winter pea forage exist, but within our study, organic winter pea forage yields were five times greater than the conventional system yields. The conventional winter pea was more severely damaged by an early spring frost, while according to visual observations (personal communication, Dennis Pitman) greater weed presence in the organic systems protected the pea crop. Our results confirm that of others in the Northwestern U.S. Earlier studies from the Boyd cropping system plots reported organic winter crops to be higher yielding than spring crops (Gallagher et al., 2010; Borrelli et al., 2012), and that organic winter wheat is competitive with regional conventional yields (Miller et al., 2008). Organic spring wheat was not as successful.

2.5 Conclusion

Overall, the ORT systems highlighted in this study support that crop yields and factors of soil health are similar or improved compared to the non-organic no-tillage system. Greater earthworm population density in Org-WPW compared to Con-WPW indicates that the combination of organic inputs and elimination of pesticides can offset the effect of more intensive cultivation on endogeic earthworm (*A. trapezoides*) when disturbance is limited to shallow depths. Measuring the impact that earthworms may have on soil physical properties at the field scale can be a challenge, as was observed by (Wuest, 2001). We may not have been able to capture their impact by using random placement of point measurements, such as with field measurement of hydraulic conductivity, or samples removed for lab testing of aggregate stability and bulk density. Differences in soil biological and chemical aspects of soil health emerged due to management effects, and were restricted to the upper soil horizons, as has been observed by other ORT studies (Carr et al., 2013).

A better understanding of the thresholds for inputs that drive necessary functions in agroecoysystems, such as the balance between organic matter and tillage, may further improve the efficiency and sustainability of organic agriculture. The amount of tillage in the organic systems in this experiment appears to be below the threshold for causing negative impacts to soil health, or is balanced by other aspects of management, at least in the medium term (11 years). This is supported by others who have observed that differences in soil structure (Papadopoulos et al., 2006), SOC (Fließbach et al., 2007), microbial biomass and earthworms (Mäder et al., 2002) begin to emerge after a similar length of time. Reduced tillage is necessary for minimizing erosion in Palouse arable fields, and development of successful ORT practices are recommended for integrating organic management in this region in order to maintain long-term soil health. The results of our study suggest that soil health in organic agricultural systems that receive adequate organic matter and nutrient inputs may improve under reduced tillage practices, and may be able to endure higher disturbance than conventionally managed systems. While we assessed soil disturbance in the ORT systems used in this study, a more precise analysis of the erosion potential of these systems at the field scale in Palouse silt loam soils would be advisable before it is suggested for regional use.

Table 2.1. Cropping system management: Seed variety and rate, tillage and machine operations, and fertilizer inputs

Crop System	Year	Crop, Seed variety and rate (kg ha^{-1})	Tillage and Machine operations	Fertilizer (kg ha^{-1})
Org-Alf-5yr STIR = 36	2008	Winter Barley Hesk (106)	Fall undercutter, r. harrow, r.how and spread manure 3x spring r. how, 1x swath and bale	7173 kg manure (410 kg TN, 34 kg NH$_4^+$)
	2009	Winter Triticale Trical (112)	Fall undercutter, r. harrow, r.how and spread manure 4x spring r. hoe, 1x swath and bale, 4x flail mow	7173 kg manure (410 kg TN, 34 kg NH$_4^+$)
	2010	Alfalfa hay mix Ladak alfalfa (13) Potomac Orchardgrass (9)	Fall undercutter, 2x r. harrow Spring 3 x r. hoe before planting, 2x after 1x flail mow before 1x swath and bale, 2x flail mow	--
	2011	Alfalfa (2nd yr) --	Fall 2x r. harrow Spring 3x r. hoe, 2x swath and bale, 1x flail mow	--
	2012	Alfalfa (3rd yr) --	3x spring r. hoe 2x swath and bale, 1x flail mow	--
	2013	Winter Wheat Brundage (151)	Fall undercutter, 1x r. harrow, plant Spring 4 x r. hoe, 1x flail mow	--
Org-WPW STIR = 44	2008	HR Spring Wheat Tara 2002 (112)	Fall undercutter, r. harrow, r. hoe and manure Spring 1x r. harrow, 3x r. how 1x swath and bale (weedy)	7173 kg manure (410 kg TN, 34 kg NH$_4^+$)
	2009	Winter Pea Hay Austrian (151)	Fall undercutter, 2x r. harrow Spring 4x r. hoe, 1x swath and bale, 2x flail mow, 1 x undercutter	--
	2010	Winter Wheat Brundage (151)	Fall undercutter, 2x r. harrow and manure, plant Spring 3 x r. hoe	7173 kg manure (410 kg TN, 34 kg NH$_4^+$)
	2011	Spring Wheat Kelse (168)	Fall undercutter, 2x r. harrow Spring 3x r. hoe (spring spread manure)	4770 kg manure (273 kg TN, 22 kg NH$_4^+$)
	2012	Winter Pea hay Windham (235)	Spring 3 x r. hoe 1x swath and bale, 1x flail mow	--
	2013	Winter Wheat Brundage (151)	Fall undercutter, 1x r. harrow and manure 4x r. hoe, 1x flail mow	4463 kg manure (256 kg TN, 21 kg NH$_4^+$)

(Table 2.1 cont.)

Crop System	Year	Crop, Seed variety and rate (lbs/acre)	Plant, Tillage and harvest	Fertilizer (kg ha^{-1})
Con-WPW STIR = 25	2008	HR Spring Wheat Tara 2002 (112)	Spring plant & fertilize, spray herbicide (Achieve + Supercharge), 1x swath and bale[d]	168 kg N (46-0-0, urea); 9 N, 5 kg P (16-20-0 ammonia)
	2009	Winter Pea Hay Austrian (151)	Fall plant. Spring spray herbicide: (Glyphosate) 1x swath and bale, 1x spray, flail mow post-harvest	--
	2010	Winter Wheat Brundage (151)	Fall fertilize. Spring herbicide (Widematch, Osprey, AMS)	112 kg N (46-0-0, urea); 9 kg N, 5 kg P (16-20-0, ammonia)
	2011	HR Spring Wheat Kelse (168)	Spring 3x r. hoe, plant & fertilize, spray herbicide (Glyphosate)	112 kg N (46-0-0, urea); 9 kg N, 5 kg P (16-20-0, ammonia)
	2012	Winter Pea Hay Windham (235)	Fall plant. Spring 3x r. hoe, spray herbicide (Assure II), 1x swath and bale, 1x flail mow post-harvest	--
	2013	Winter Wheat Brundage (151)	Fall: undercutter, r. harrow, fertilize/plant. Spring: spray herbicide (Huskie, Axial XL), 1x flail mow post-harvest	112 kg N (46-0-0, urea); 9 kg N, 5 kg P (16-20-0, ammonia)

[a] The undercutter is a Haybuster undercutter.

[b] r. harrow is rotary harrow: 4.5 m “double pull” Phoenix (Excel Industries LLC: Phoenix Rotary Equipment, Waseca, MN) (Gallagher et al., 2010).

[c] r. hoe is a rotary hoe: 4.5 m M&W 15 MT (MT= minimum tillage)(M and W Gear Co., Gibson City, IL) equipped with Yetter (Yetter Manufacturing Inc., Colchester IL) helper springs to supply additional downward pressure potential to the implement (Gallagher et al., 2010).

[d] 2008 HR spring wheat was swathed and baled in order to remove weed seeds from a flush of wild oat. Crop could have been sold as grain hay.

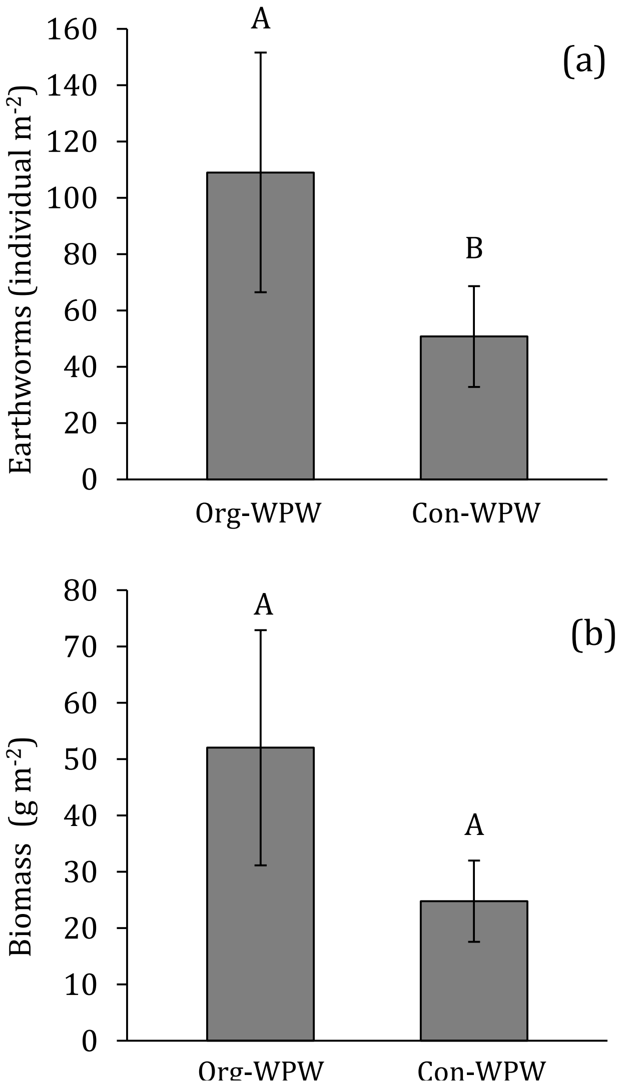


Figure 2.1: (a) Mean earthworm density (individuals m^{-2}) and (b) mean earthworm live weight biomass averaged across two sampling years in an organic (Org-WPW) and conventional (Con-WPW) three-year crop rotation (spring wheat, winter pea hay, winter wheat). Different letters indicate significant differences ($p<0.05$) ($n=5$); bars represent standard error.

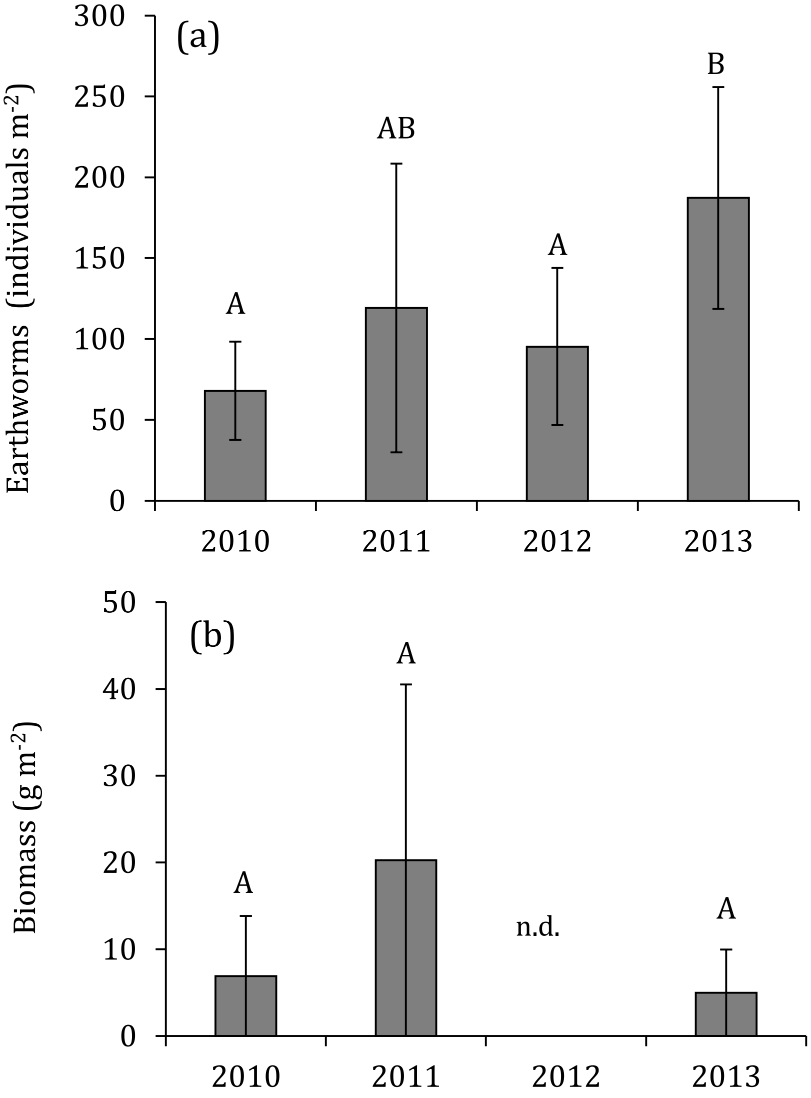


Figure 2.2 Annual (a) mean earthworm density (individuals m^{-2}) and (b) earthworm live weight biomass in an organic 5-year crop rotation (Org-Alf-5yr) (n=5). Plots were planted in perenial alfalfa-hay from 2010-2012, followed by winter wheat in 2013. Different letters indicate significant differences at $p<0.05$. Bars indicate standard error. (n.d.=no data)

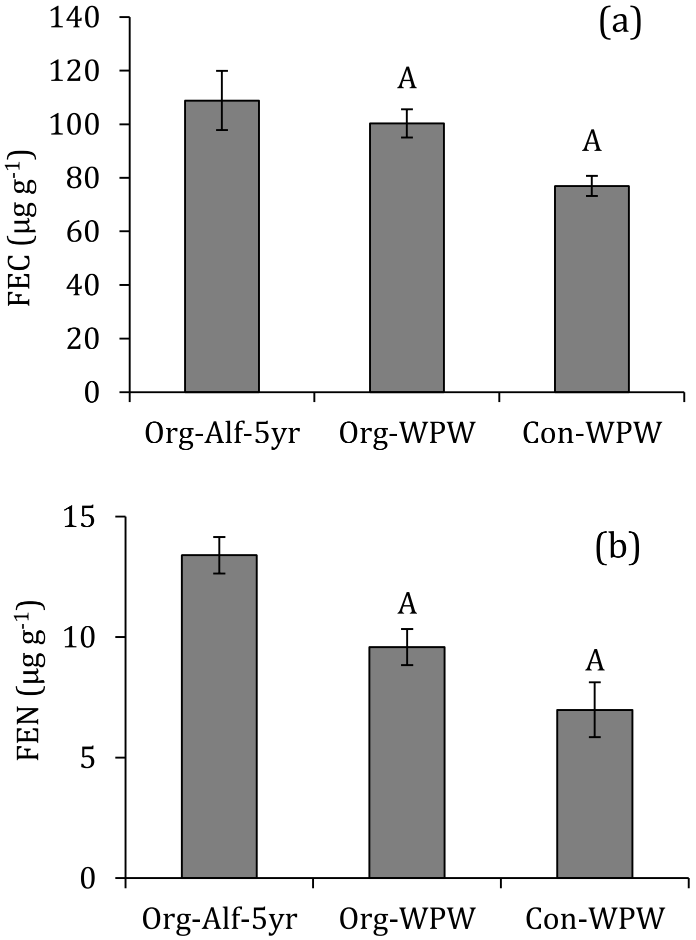


Figure 2.3. Fumigated extractable carbon (FEC) and nitrogen (FEN) in October 2013 in an organic (Org-WPW) and conventional (Con-WPW) three-year crop rotation (spring wheat, winter pea hay, winter wheat), and an organic 5-year rotation that includes three years of perennial alfalfa (Org-Alf-5yr). (a) Data suggests a non-significant trend of higher FEC in Org-WPW compared to Con-WPW (p=0.058) (b) FEN was not significantly different between Org-WPW and Con-WPW, (p=0.154). Error bars represent standard error.

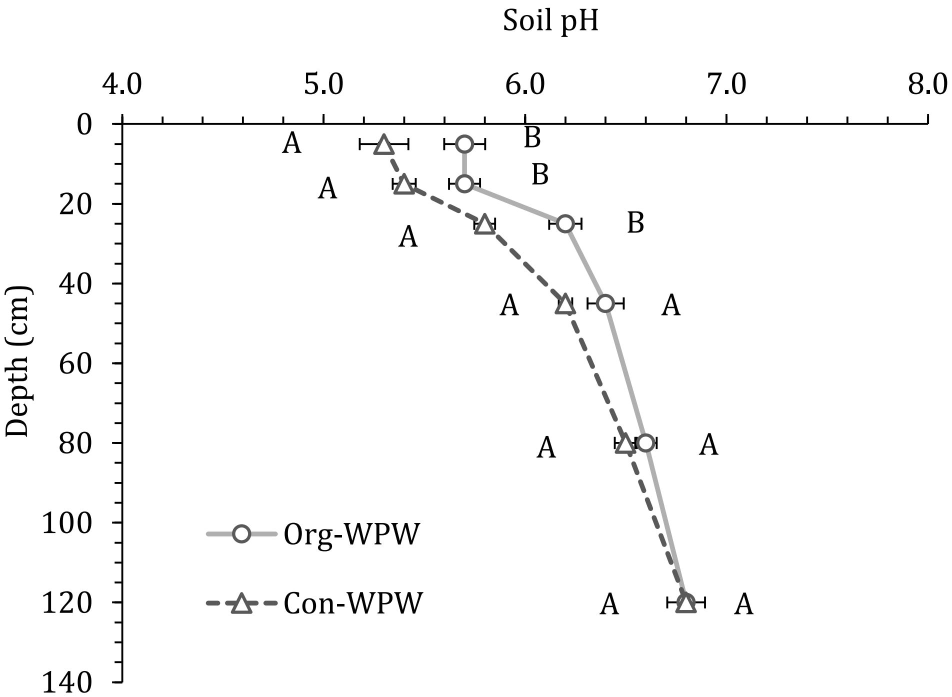


Figure 2.4. Soil pH by depth in organic (Org-WPW) and conventional (Con-WPW) 3-year crop rotations (spring wheat, winter pea hay, winter wheat) (n=5). Significant main effects of cropping system were observed (p=0.005) for the full soil profile. Cropping system*depth interactions were significant for 0 – 10, 10 – 20, 20 – 30 cm of soil. Soil pH in Org-Alf-5yr was ± 0.1 pH to that of Org-WPW at all depths except from 100-140 cm (pH in Org-Alf-5y = 7.1, data not shown). Different letters indicate significant cropping system*depth difference ($p<0.05$); standard error indicated by bars.

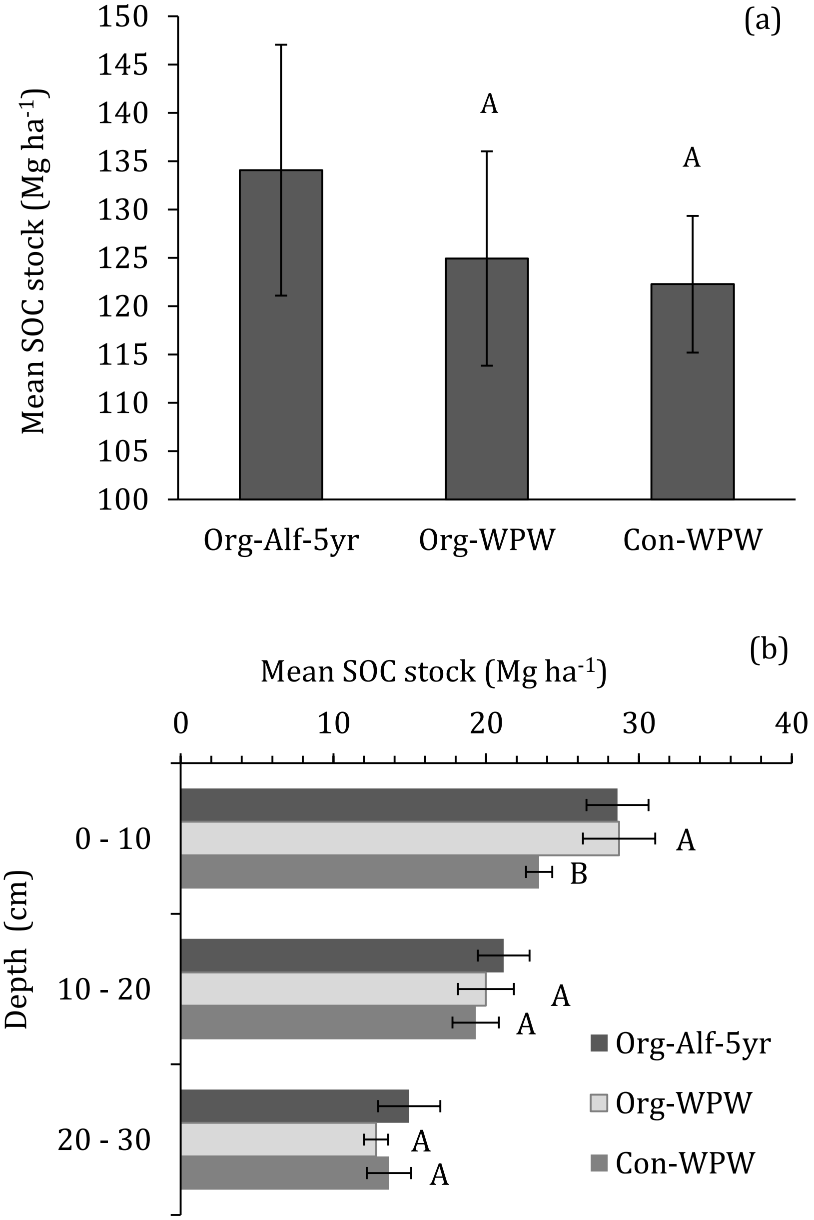


Figure 2.5. Mean SOC stocks (Mg ha^{-1}) in two, 3-year cropping systems under organic (Org-WPW) and conventional (Con-WPW) management, and an organic 5-year rotation that includes three years of perennial alfalfa (Org-Alf-5yr): (a) cumulative SOC to 1.4 m soil depth and (b) mean SOC from 0 – 30 cm. Significant differences indicated by different letters ($p<0.05$). Error bars indicate standard error.

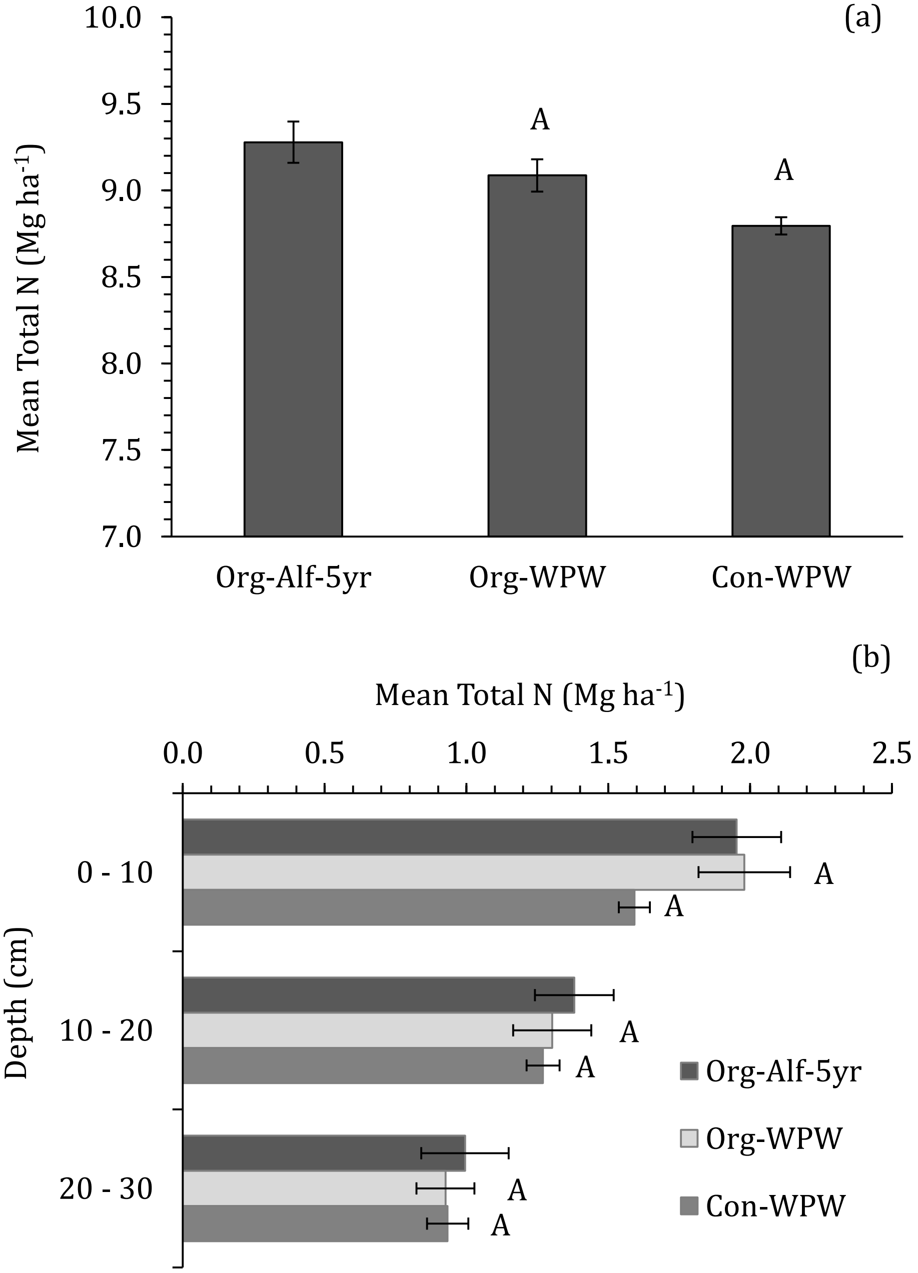


Figure 2.6. Mean total N stocks (Mg ha^{-1}) in two, 3-year cropping systems under organic (Org-WPW) and conventional (Con-WPW) management, and an organic 5-year rotation that includes three years of perennial alfalfa (Org-Alf-5yr): (a) cumulative total N to 1.4 m soil depth and (b) mean total N from 0 – 30 cm. Significant differences indicated by different letters ($p<0.05$). Error bars indicate standard error.

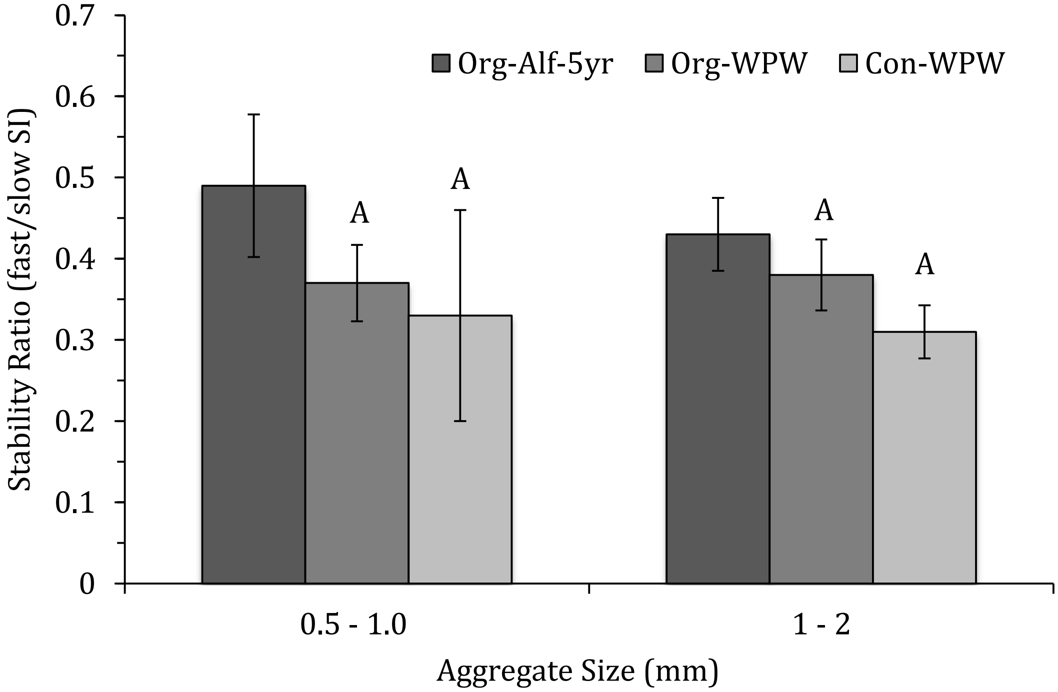


Figure 2.7. Stability ratios for small (0.5 – 1 mm) and large (1 – 2 mm) soil aggregate size ranges from two, 3-year cropping systems under organic (Org-WPW) and conventional (Con-WPW) management, and an organic 5-year rotation that includes three years of perennial alfalfa (Org-Alf-5yr). SI= stability index for fast and slow wetting rates. Same letters within an aggregate size range indicate no significant difference in cropping system ($p<0.05$). Bars indicate standard error.

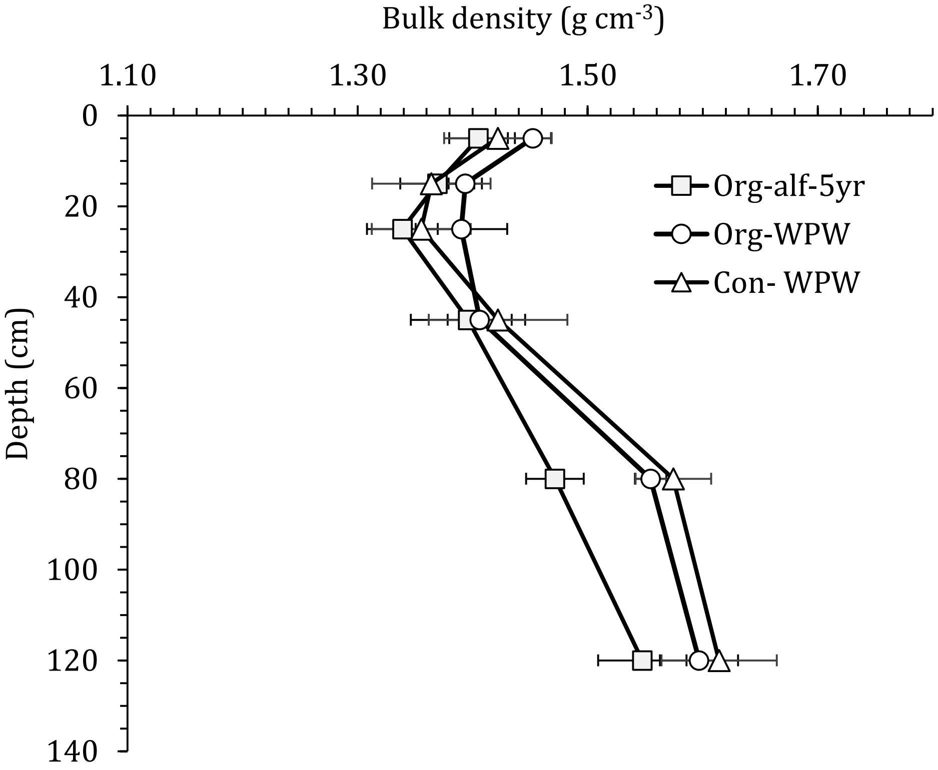


Figure 2.8. Soil bulk density (g cm^{-3}) measured in two, 3-year cropping systems under organic (Org-WPW) and conventional (Con-WPW) management, and an organic 5-year rotation that includes three years of perennial alfalfa (Org-Alf-5yr). Main effects of cropping systems and cropping system*depth interactions were not significantly different ($p<0.05$). Bars indicate standard error.

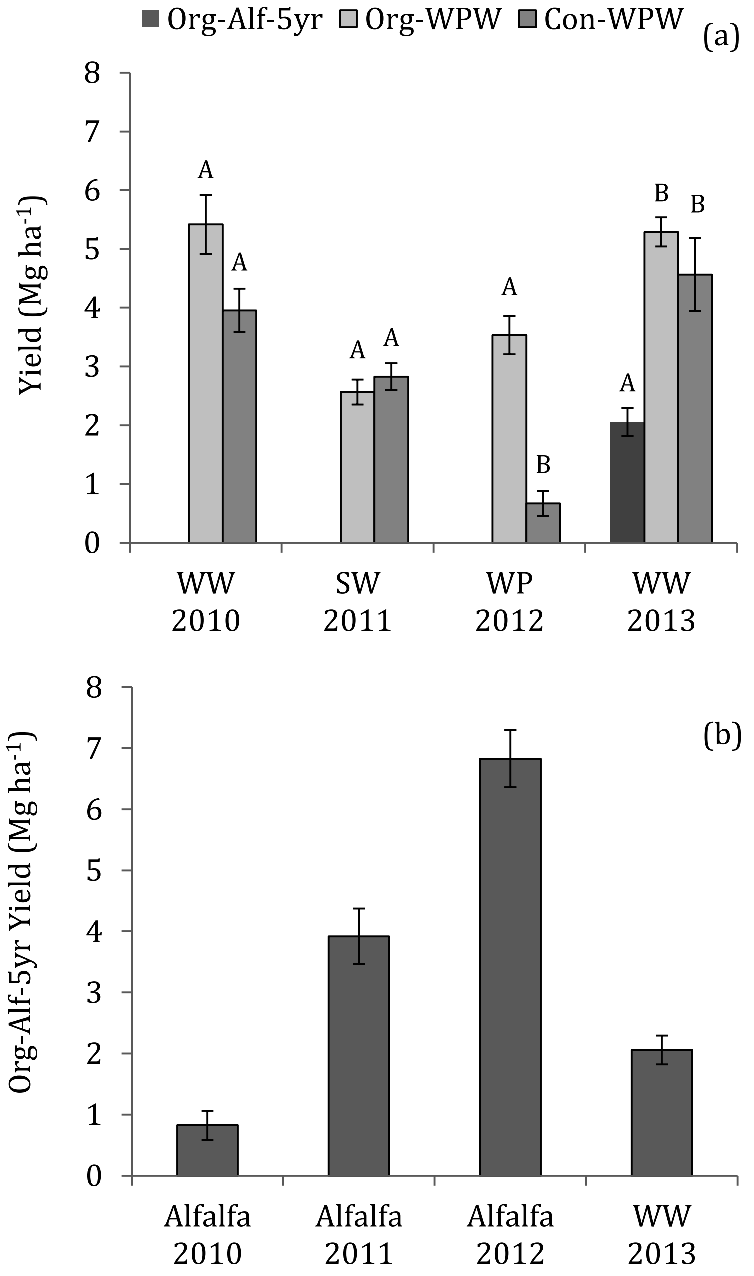


Figure 2.9. Crop yield from three cropping systems from 2010 – 2013 (WW=winter wheat, SW=spring wheat, WP=winter pea hay, Alfalfa = alfalfa-orchardgrass mix) for (a) Org-WPW and Con-WPW that follow the same crop rotation. Org-Alf-5yr WW yields were included for yield comparison in 2013. Crop yield was not significantly different between Org-WPW and Con-WPW in all years except for 2012 WP ($p<0.01$). In 2013, WW yields were higher in Org-WPW and Con-WPW compared to Org-Alf-5yr ($p<0.01$). (b) Org-Alf-5yr crop yields from 2010 – 2013. Bars indicate standard error.

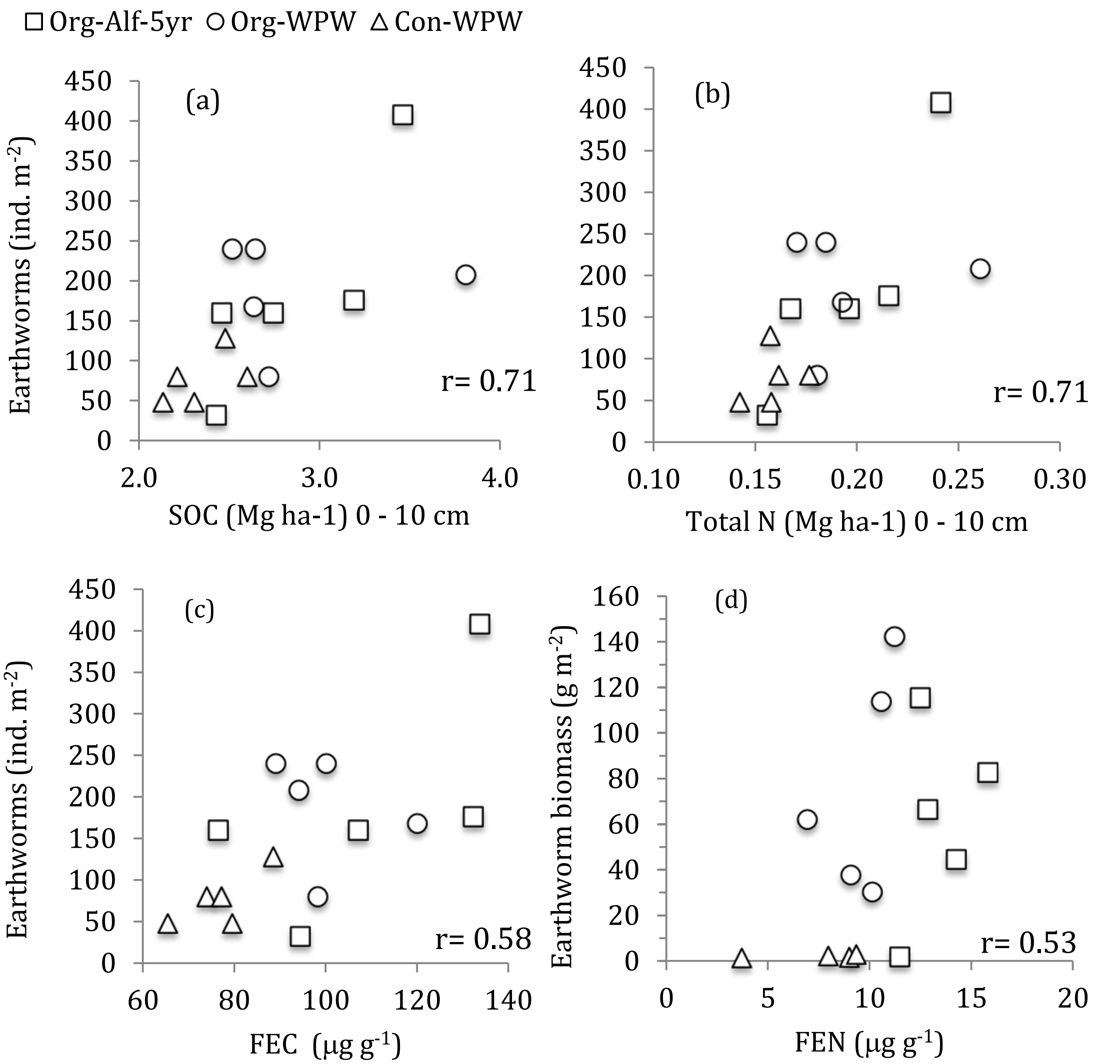


Figure 2.10. Combined across all cropping systems (Org-WPW, Con-WPW, Org-Alf-5yr) correlation between (a) earthworm density and SOC stocks (b) earthworm density and total N stocks (c) earthworm density and FEC and (d) earthworm biomass and FEN were significant ($p<0.05$) (r=Spearman rank coefficient).

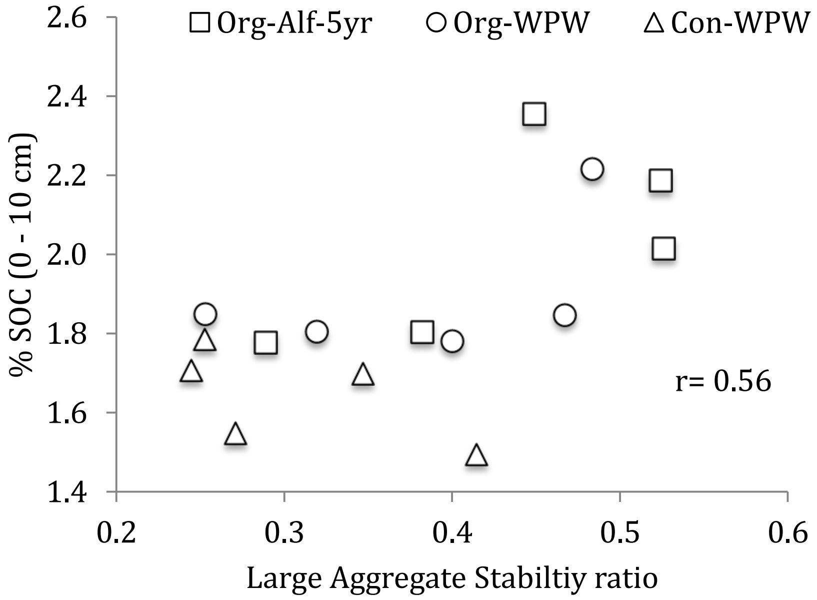


Figure 2.11. Combined across all cropping systems, correlation between % SOC in the top 10 cm of soil and large aggregate stability ratio (1 – 2 mm aggregates) was significant ($P<0.05$, Spearman rank coefficient $r=0.56$).

2.6 References

Anderson, R.L. 2010. A rotation design to reduce weed density in organic farming. Renew. Agric. Food Syst. 25(3): 189–195.

Berner, A., I. Hildermann, A. Fließbach, L. Pfiffner, U. Niggli, and P. Mader. 2008. Crop yield and soil fertility response to reduced tillage under organic management. Soil Tillage Res. 101(1-2): 89–96.

Berthrong, S.T., D.H. Buckley, and L.E. Drinkwater. 2013. Agricultural management and labile carbon additions affect soil microbial community structure and interact with carbon and nitrogen cycling. Microb. Ecol. 66(1): 158–70.

Birkhofer, K., T.M. Bezemer, J. Bloem, M. Bonkowski, S. Christensen, D. Dubois, F. Ekelund, A. Fließbach, L. Gunst, K. Hedlund, P. Mäder, J. Mikola, C. Robin, H. Setälä, F. Tatin-Froux, W.H. Van der Putten, and S. Scheu. 2008. Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Soil Biol. Biochem. 40(9): 2297–2308.

Blagodatskaya, E., and Y. Kuzyakov. 2008. Mechanisms of real and apparent priming effects and their dependence on soil microbial biomass and community structure: critical review. Biol. Fertil. Soils 45(2): 115–131.

Blouin, M., M.E. Hodson, E. a. Delgado, G. Baker, L. Brussaard, K.R. Butt, J. Dai, L. Dendooven, G. Peres, J.E. Tondoh, D. Cluzeau, and J.-J. Brun. 2013. A review of earthworm impact on soil function and ecosystem services. Eur. J. Soil Sci. 64(2): 161–182.

Bohlen, P.J., C. a. Edwards, Q. Zhang, R.W. Parmelee, and M. Allen. 2002. Indirect effects of earthworms on microbial assimilation of labile carbon. Appl. Soil Ecol. 20(3): 255–261.

Borrelli, K., R. Koenig, R.S. Gallagher, D. Pittmann, A. Snyder, I. Burke, L. Hoagland, and E.P. Fuerst. 2012. Alternative strategies for transitioning to rrganic production in direct-seeded grain systems in eastern Washington II: Nitrogen fertility. J. Sustain. Agric. 36(4): 461–477.

Brown, G.G., and B.M. Doube. 2004. Functional interactions between earthworms, microorganisms, organic matter, and plants. p. 213–239. *In* Edwards, C.A. (ed.), Earthworm Ecology, Second Edition. second. CRC Press, LLC, New York.

Callaham Jr., M.A., and P.F. Hendrix. 1997. Relative abundance and seasonal activity of earthworms (Lumbricidae and megascolecidae) as determined by hand-sorting and formalin extraction in forest soils on the southern Appalachian Piedmont. Soil Biol Biochem 29(3/4): 317–321.

Carpenter-Boggs, L., A.C. Kennedy, and J.P. Reganold. 2000. Organic and biodynamic management: Effects on soil biology. Soil Sci. Soc. Am. J. 64`(Sept-Oct): 1651–1659.

Carr, P., G. Gramig, and M. Liebig. 2013. Impacts of organic zero tillage systems on crops, weeds, and soil quality. Sustainability 5(7): 3172–3201.

Carr, P.M., P. Mäder, N.G. Creamer, and J.S. Beeby. 2012. Editorial: Overview and comparison of conservation tillage practices and organic farming in Europe and North America. Renew. Agric. Food Syst. 27(01): 2–6.

Castellanos-Navarrete, A., C. Rodríguez-Aragonés, R.G.M. de Goede, M.J. Kooistra, K.D. Sayre, L. Brussaard, and M.M. Pulleman. 2012. Earthworm activity and soil structural changes under conservation agriculture in central Mexico. Soil Tillage Res. 123: 61–70.

Chan, K.Y. 2001. An overview of some tillage impacts on earthworm population abundance and diversity - implications for functioning in soils. Soil Tillage Res. 57: 179–191.

Chan, K.Y., D.P. Heenan, and R. Ashley. 1994. Seasonal changes in surface aggregate stability under different tillage and crops. Soil Tillage Res. 28: 301–314.

Cheng-Liang, L., X. Jiang-Bing, H. Yuan-Qiu, L. Yan-Li, and F. Jian-Bo. 2012. Dynamic relationship between biologically active soil organic carbon and aggregate stability in long-term organically fertilized soils. Pedosphere 22(5): 616–622.

Chenu, C., Y. Le Bissonnais, and D. Arrouays. 2000. Organic matter influence on clay wettability and soil aggregate stability. Soil Sci. Soc. Am. J. 64: 1479–1486.

Clark, M.S., W.R. Horwath, C. Shennan, and K.M. Scow. 1998. Changes in soil chemical properties resulting from organic and low-input farming practices. Agron. J. 90: 662–671.

Collis-George, N., and B.S. Figueroa. 1984. The use of high energy moisture characteristic to assess soil stability. Aust. J. Soil Res. 22-23: 349–356.

Crittenden, S.J., T. Eswaramurthy, R.G.M. De Goede, L. Brussaard, and M.M. Pulleman. 2014. Effect of tillage on earthworms over short- and medium-term in conventional and organic farming. Appl. Soil Ecol.

Curry, J.P., and O. Schmidt. 2007. The feeding ecology of earthworms – A review. Pedobiologia (Jena). 50(6): 463–477.

Delate, K., D. Cwach, and C. Chase. 2012. Organic no-tillage system effects on soybean, corn and irrigated tomato production and economic performance in Iowa, USA. Renew. Agric. Food Syst. 27(01): 49–59.

Van Diepeningen, A.D., O.J. de Vos, G.W. Korthals, and A.H.C. van Bruggen. 2006. Effects of organic versus conventional management on chemical and biological parameters in agricultural soils. Appl. Soil Ecol. 31(1-2): 120–135.

Doran, J.W., and M.R. Zeiss. 2000. Soil health and sustainability: Managing the biotic component of soil quality. Appl. Soil Ecol. 15(1): 3–11.

Drinkwater, L.E., R.R. Janke, and L. Rossoni-Longnecker. 2000. Effects of tillage intensity on nitrogen dynamics and productivity in legume-based grain systems. Plant Soil 227: 99–113.

Drinkwater, L.E., P. Wagoner, and M. Sarrantonio. 1998. Legume-based cropping systems have reduced carbon and nitrogen losses. Nature 396(November).

Edwards, C.A., and P.J. Bohlen. 1996. Biology and Ecology of Earthworms. Third edit. Chapman & Hall, New York.

Edwards, C.A., P.J. Bohlen, D.R. Linden, and S. Subler. 1995. Earthworms in Agroecosystems. p. 185–214. *In* Hendrix, P.F. (ed.), Earthworm Ecology and Biogeography in North America. CRC Press, Inc.

Elmholt, S., P. Schjønning, L.J. Munkholm, and K. Debosz. 2008. Soil management effects on aggregate stability and biological binding. Geoderma 144(3-4): 455–467.

Elrick, D.E., W.D. Reynolds, and K.A. Tan. 1989. Hydraulic conductivity , measurements in the unsaturated zone using improved well analyses. Ground Water Monit. Remediat. 9(3): 184–193.

Entz, M.H., R. Guilford, and R. Gulden. 2001. Crop yield and soil nutrient status on 14 organic farms in the eastern portion of the northern Great Plains. Can. J. Plant Sci. 81(2): 351–354.

Ernst, G., and C. Emmerling. 2009. Impact of five different tillage systems on soil organic carbon content and the density, biomass, and community composition of earthworms after a ten year period. Eur. J. Soil Biol. 45(3): 247–251.

Fauci, M.F., and D.F. Bezdicek. 2002. Lumbricid earthworms in the Palouse region. Northwest Sci. Notes 76(3).

Fließbach, A., H.-R. Oberholzer, L. Gunst, and P. Mäder. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118: 273–284.

Gadermaier, F., A. Berner, A. Fließbach, J.K. Friedel, and P. Mäder. 2012. Impact of reduced tillage on soil organic carbon and nutrient budgets under organic farming. Renew. Agric. Food Syst. 27(01): 68–80.

Gallagher, R.S., D. Pittmann, A.M. Snyder, R.T. Koenig, E.P. Fuerst, I.C. Burke, and L. Hoagland. 2010. Alternative strategies for transitioning to organic production in direct-seeded grain systems in eastern Washington I: Crop agronomy. J. Sustain. Agric. 34(5): 483–503.

Gerhardt, R.A. 1997. A comparative analysis of the effects of organic and conventional farming systems on soil structure. Biol. Agric. Hortic. 14: 139–157.

Grandy, a. S., G.P. Robertson, and K.D. Thelen. 2006. Do productivity and environmental trade-offs justify periodically cultivating no-till cropping systems? Agron. J. 98(6): 1377–1383.

Grossman, R.., and T.G. Reinsch. 2002. The solid phase: Bulk density and linear extensibility. p. 201–228. *In* Methods of Soil Analysis Part 4--Physcial Methods. SSSA Book. Soil Society of America, Inc., Madison, WI.

Gunapala, N., and K.M. Scow. 1998. Dynamics of soil microbial biomass and activity in conventional and organic farming systems. Soil Biol. Biochem. 30(6): 805–816.

Hansen, N.C., B.L. Allen, R.L. Baumhardt, and D.J. Lyon. 2012. Research achievements and adoption of no-till, dryland cropping in the semi-arid U.S. Great Plains. F. Crop. Res. 132: 196–203.

Harris, G.H., and O.B. Hesterman. 1990. Quantifying the nitrogen contribution from alfalfa to soil and two succeeding crops using nitrogen-15. Agron. J. 81(1): 129–134.

Jänsch, S., G.K. Frampton, J. Römbke, P.J. Van den Brink, and J.J. Scott-Fordsmand. 2006. Effects of pesticides on soil invertebrates in model ecosystem and field studies: A review and comparison with laboratory toxicity data. Environ. Toxicol. Chem. 25(9): 2490–2501.

Johnson-Maynard, J.L., K.J. Umiker, and S.O. Guy. 2007. Earthworm dynamics and soil physical properties in the first three years of no-till management. Soil Tillage Res. 94(2): 338–345.

Kemper, W.D., and R.C. Rosenau. 1986. Aggregate stability and size distribution. p. 425–442. *In* Klute, A. (ed.), Methods of Soil Analysis: Part 1, Physical and Mineralogical Methods. Second Edi. Soil Society of America, Madison.

Ketterings, Q.M., J.M. Blair, and J.C.. Marinissen. 1997. Effects of earthworms on soil aggregate stability and carbon and nitrogen storage in a legume cover crop agroecosystem. Soil Biol. Biochem. 29(3/4): 401–408.

Kibblewhite, M.G., K. Ritz, and M.J. Swift. 2008. Soil health in agricultural systems. Philos. Trans. R. Soc. Lond. B. Biol. Sci. 363(1492): 685–701.

Kok, H., R.I. Papendick, and K.E. Saxton. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. J. Soil Water Conserv. 64(4): 253–264.

Kramer, S.B., J.P. Reganold, J.D. Glover, B.J.M. Bohannan, and H. a Mooney. 2006. Reduced nitrate leaching and enhanced denitrifier activity and efficiency in organically fertilized soils. Proc. Natl. Acad. Sci. U. S. A. 103(12): 4522–7.

Lavelle, P. 1997. Faunal activities and soil processes: Adaptive strategies that determine ecosystem function. Adv. Ecol. Res.: 93–132.

Lee, K.E. 1995. Earthworms and sustainable land use. p. 215–234. *In* Hendrix, P.F. (ed.), Earthworm Ecology and Biogeography in North America. Lewis Publishers, Ann Arbor.

Luna, J.M., J.P. Mitchell, and A. Shrestha. 2012. Conservation tillage for organic agriculture: Evolution toward hybrid systems in the western USA. Renew. Agric. Food Syst. 27(01): 21–30.

Lynch, J.M., and L.F. Elliott. 1983. Aggregate stabilization of volcanic ash and soil during microbial degradation of straw. Appl. Environ. Microbiol. 45(4): 1398–401.

Mäder, P., and A. Berner. 2012. Development of reduced tillage systems in organic farming in Europe. Renew. Agric. Food Syst. 27(01): 7–11.

Mäder, P., A. Fließbach, D. Dubois, L. Gunst, P. Fried, and U. Niggli. 2002. Soil fertility and biodiversity in organic farming. Science 296(5573): 1694–7.

Malhi, S.S., R. Lemke, Z.H. Wang, and B.S. Chhabra. 2006. Tillage, nitrogen and crop residue effects on crop yield, nutrient uptake, soil quality, and greenhouse gas emissions. Soil Tillage Res. 90(1-2): 171–183.

Marinari, S., R. Mancinelli, E. Campiglia, and S. Grego. 2006. Chemical and biological indicators of soil quality in organic and conventional farming systems in Central Italy. Ecol. Indic. 6(4): 701–711.

Marinari, S., G. Masciandaro, B. Ceccanti, and S. Grego. 2000. Influence of organic and mineral fertilizers on soil biological and physical properties. Bioresour. Technol. 72: 9–17.

Marinissen, J.C.Y. 1992. Population dynamics of earthworms in a silt loam soil under conventional and “integrated” arable farming during two years with different weather patterns. Soil Biol Biochem 24(12): 1647–1654.

Marriott, E.E., and M.M. Wander. 2006. Total and labile soil organic matter in organic and conventional farming systems. Soil Sci. Soc. Am. J. 70: 950–959.

McCool, D.K., D.R. Huggins, K.E. Saxton, and A.C. Kennedy. 2001. Factors affecting agricultural sustainability in the Pacific Northwest , USA: An overview. p. 255–260. *In* Sustaining the Global Farm. Selected papers from the 10th International Soil

Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

McCune, B., and J.B. Grace. 2002. Data Transformations. p. 67–79. *In* Analysis of Ecological Communities. MjM Software Design, Gleneden Beach, Oregon.

McGill, W.B., K.R. Cannon, J.A. Robertson, and F.D. Cook. 1986. Dynamics of soil microbial biomass and water-soluble organic C in Breton L after 50 years of cropping to two rotations. Can. J. Soil Sci. 66(1): 1–19.

Miller, P.R., D.E. Buschena, C. a. Jones, and J. a. Holmes. 2008. Transition from intensive tillage to no-tillage and organic diversified annual cropping systems. Agron. J. 100(3): 591–599.

National Oceanic and Atmospheric Administration (NOAA). 2014. National Climate Data Center. Data Tools 1981 - 2010 Norm.Available at http://www.ncdc.noaa.gov/cdo-web/datatools/normals (verified 23 July 2014).

Palm, C., H. Blanco-Canqui, F. DeClerck, L. Gatere, and P. Grace. 2014. Conservation agriculture and ecosystem services: An overview. Agric. Ecosyst. Environ. 187: 87–105.

Papadopoulos, A., N.R.A. Bird, A.P. Whitmore, and S.J. Mooney. 2006. The effects of organic farming on the soil physical environment. Asp. Appl. Biol. 79: 263–267.

Papendick, R.I. 1996. Farming systems and conservation needs in the Northwest Wheat Region. Am. J. Altern. Agric. 11: 52–57.

Peigné, J., B.C. Ball, J. Roger-Estrade, and C. David. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Manag. 23(2): 129–144.

Peigné, J., M. Cannavaciuolo, Y. Gautronneau, a. Aveline, J.L. Giteau, and D. Cluzeau. 2009. Earthworm populations under different tillage systems in organic farming. Soil Tillage Res. 104(2): 207–214.

Pelosi, C., L. Toutous, F. Chiron, F. Dubs, M. Hedde, a. Muratet, J.-F. Ponge, S. Salmon, and D. Makowski. 2013. Reduction of pesticide use can increase earthworm populations in wheat crops in a European temperate region. Agric. Ecosyst. Environ. 181: 223–230.

Peoples, M.B., D.F. Herridge, B.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khans, B.S. Jensen, P. Industry, G.P.O. Box, S. Asia, S. Asia, S. Asia, S. Asia, S. Asia, and S. Asia. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48: 1–17.

Pfiffner, L., and H. Luka. 2007. Earthworm populations in two low-input cereal farming systems. Appl. Soil Ecol. 37(3): 184–191.

Pfiffner, L., and P. Mäder. 1997. Effects of biodynamic, organic and conventional production systems on earthworm populations. Biol. Agric. Hortic. An Int. J. Sustain. Prod. Syst. 15(1-4): 2–10.

Pierson, F.B., and D.J. Mulla. 1989. An improved method for measuring aggregate stability of a weakly aggregated loessial soil. Soil Sci. Soc. Am. J. 53(Nov.-Dec. 1989): 1825–1831.

Pierson, F.B., and D.J. Mulla. 1990. Aggregate stability in the Palouse region of Washington: Effect of landscape position. Soil Sci. Soc. Am. J. 54: 1407–1412.

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55(7): 573–582.

De Ponti, T., B. Rijk, and M.K. van Ittersum. 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108: 1–9.

Pulleman, M., a. Jongmans, J. Marinissen, and J. Bouma. 2003. Effects of organic versus conventional arable farming on soil structure and organic matter dynamics in a marine loam in the Netherlands. Soil Use Manag. 19(2): 157–165.

Purakayastha, T.J., J.L. Smith, and D.R. Huggins. 2009. Microbial biomass and N cycling under native prairie, conservation reserve and no-tillage in Palouse soils. Geoderma 152(3-4): 283–289.

Reganold, J.P. 1988. Comparison of soil properties as influenced by organic and conventional farming systems. Am. J. Altern. Agric. 3(4): 144–145.

Reganold, J.P., A.S. Palmer, J.C. Lockhart, and A.N. Macgregor. 1993. Soil quality and financial performance of biodynamic and conventional farms in New Zealand. Science (80-.). 260(5106): 344–349.

Reynolds, W.D. 2008. Saturated hydraulic properties: Well permeameter. p. 1025–1042. *In* Carter, M.R., Gregorich, E.G. (eds.), Soil Sampling and Methods of Analysis. Second Edi. Canadian Society of Soil Science, Boca Raton.

Rochette, P., and E.G. Gregorich. 1998. Dynamics of soil microbial biomass C, soluble organic C and CO2 evolution after three years of manure application. Can. J. Soil Sci. 78: 283–290.

Santos, V.B., A.S.F. Araújo, L.F.C. Leite, L.A.P.L. Nunes, and W.J. Melo. 2012. Soil microbial biomass and organic matter fractions during transition from conventional to organic farming systems. Geoderma 170(null): 227–231.

Schaefer, J., R. Hybner, and J. Miller. 2005. Enterprise costs and returns for different cropping and tillage systems in southeastern Montana and southwestern North Dakota, NRCS-MT-Economics Tech Note 6.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2003. Dryland Cropping in the Western United States. *In* Pacific Northwest Conservation Tillage Systems Handbook Series No. 28.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2006. Dryland Cropping in the Western United States. p. 365–394. *In* Peterson, G.A., Unger, P.W., Payne, W.A. (eds.), Dryland Agriculture: Agronomy Monograph no. 23, 2nd Ed. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, WI.

Schmidt, O., R.. Clements, and G. Donaldson. 2003. Why do cereal–legume intercrops support large earthworm populations? Appl. Soil Ecol. 22: 181–190.

Schwert, D.P. 1990. Oligochaeta: Lumbricidae. p. 341–356. *In* Dindal, D.L. (ed.), Soil Biology Guide. John Wiley & Sons, New York.

Shepherd, M.A., R. Harrison, and J. Webb. 2002. Managing soil organic matter – implications for soil structure on organic farms. Soil Use Manag. 18(3): 284–292.

Shiralipour, A., D.B. McConnell, and W.H. Smith. 1992. Physical and chemical properties of soils as affected by municipal solid waste compost application. Biomass and Bioenergy 3(3-4): 261–266.

Singh, B., and S.S. Malhi. 2006. Response of soil physical properties to tillage and residue management on two soils in a cool temperate environment. Soil Tillage Res. 85(1-2): 143–153.

Soil Moisture Equipment Crop. 2012. Operating instructions: Guelph Permeameter, 2800. (December): 1–60.

Soil Survey Laboratory Staff. 2004. Soil Survey Laboratory Methods Manual. Soil Survey Investigations Report No.42, Version 4.0. National Soil Survey Center, Lincoln, NE.

Soil Survey staff. 2013. Web Soil Survey. Natural Resources Conservation Service, United States Department of Agriculture. Available at http://websoilsurvey.nrcs.usda.gov/ (verified 14 February 2014).

Stark, C.H., L.M. Condron, M. O'Callaghan, A. Stewart, and H.J. Di. 2008. Differences in soil enzyme activities, microbial community structure and short-term nitrogen mineralisation resulting from farm management history and organic matter amendments. Soil Biol. Biochem. 40(6): 1352–1363.

Stark, C., L.M. Condron, a. Stewart, H.J. Di, and M. O'Callaghan. 2007. Influence of organic and mineral amendments on microbial soil properties and processes. Appl. Soil Ecol. 35(1): 79–93.

Stockdale, E. 2011. Organic farming: Pros and cons for soil health and climate change. p. 317–343. *In* Bhupinder Pal Singh, Annette L. Cowie, K.Y.C. (ed.), Soil Health and Climate Change. Springer, New York.

Stockdale, E.A., and C.A. Watson. 2009. Biological indicators of soil quality in organic farming systems. Renew. Agric. Food Syst. 24(4): 308–318.

Tisdall, J., and M. Oades. 1982. Organic matter and water-stable aggregates in soils. J. Soil Sci. 33: 141–163.

Umiker, K.J., J.L. Johnson-Maynard, T.D. Hatten, S.D. Eigenbrode, and N. a. Bosque-Pérez. 2009. Soil carbon, nitrogen, pH, and earthworm density as influenced by cropping practices in the Inland Pacific Northwest. Soil Tillage Res. 105(2): 184–191.

USDA-National Organic Program (NOP). 2014. No Title. Available at http://www.ams.usda.gov/AMSv1.0/nop (verified 15 February 2014).

USDA-NOP. 2013. USDA Organic Regulations. National Organic Program, U.S.

USDA-NRCS. 2005. Soil Tillage Intensity Rating (STIR).

USDA-NRCS. 2006. Technical notes: The Soil Tillage Intensity Rating (STIR). TN agrononmy No. 50.

Voroney, R.., P.C. Brooks, and R.P. Beyaert. 2008. Soil Microbial Biomass C, N, P and S. p. 637–651. *In* Carter, M.R., Gregorich, E.G. (eds.), Soil Sampling and Methods of Analysis. Second. Canadian Society of Soil Science, Boca Raton.

Washington State University AgWeatherNet. 2013. Washington Agricultural Weather Netweork. Available at www.weather.wsue.edu/awn.php (verified 3 January 2014).

Watson, C.A., D. Atkinson, P. Gosling, L.R. Jackson, and F.W. Rayns. 2002. Managing soil fertility in organic farming systems. Soil Use Manag. 18(3): 239–247.

Whalen, J.K., and R.W. Parmelee. 2000. Earthworm secondary production and N flux in agroecosystems: A comparison of two approaches. Oecologia 124(4): 561–573.

Whalen, J.K., R.W. Parmelee, D. a. McCartney, and J.L. Vanarsdale. 1999. Movement of N from decomposing earthworm tissue to soil, microbial and plant N pools. Soil Biol. Biochem. 31(4): 487–492.

Wortman, S.E., T.D. Galusha, S.C. Mason, and C. a. Francis. 2011. Soil fertility and crop yields in long-term organic and conventional cropping systems in Eastern Nebraska. Renew. Agric. Food Syst. 27(03): 200–216.

Wuest, S.B. 2001. Earthworm, infiltration, and tillage relationships in a dryland pea–wheat rotation. Appl. Soil Ecol. 18(2): 187–192.

Wysocki, D.J., L.K. Lutcher, D.A. Horneck, J.M. Hart, and S.E. Petrie. 2005. Winter wheat and spring grains in continuous cropping systems, FG 81-E.

Youker, R.E., and J.L. McGuiness. 1956. A short method of obtaining mean weight-diameter values of aggregate analyses of soils. Soil Sci. 83: 281–294.

Chapter 3: Economic feasibility of organic dryland crop rotations in the Palouse

3.1 Introduction

The Palouse region of the Inland Pacific Northwest (IPNW), including areas of Northwest Idaho, eastern Washington, and northeastern Oregon, is recognized for record high wheat yields (Schillinger et al., 2006). This region, characterized by its hilly landscape and deep loess soils, has also experienced historically high rates of soil erosion, causing conservation efforts to focus on minimizing soil loss through the adoption of no-till practices over the past four decades (Kok et al., 2009). Some form of conservation tillage is now commonly practiced on most farms, demonstrating regional dedication to sustainable land stewardship (Kok et al., 2009).

Organic farming represents a small portion of the agricultural industry in the Palouse, accounting for less than 0.01% of total dryland acreage (wheat, barley, beans and peas) in eastern WA (Kirby and Granatstein, 2014; USDA-NASS, 2014a). Approximately 5.5 million acres in WA and 2.5 million in ID are dedicated to dryland crops (Schillinger et al., 2003) and, of this total, 92,000 acres in WA and 116,000 in ID were certified organic in 2011 (USDA-ERS, 2014a). Surveys of WA wheat growers reported only three growers that produce organic wheat (Jones et al., 2006), and while forage and wheat are among the largest organic crops in ID, they are mostly grown in the southern and eastern parts of the state (Goldberger et al., 2010). The tendency for organic management to rely on tillage for weed control and the historically high rates of soil erosion that have occurred on Palouse arable lands are likely reasons for the low organic acreage in this area. However, recent research that integrates reduced-tillage practices with organic management suggests benefits to soil health and conservation (Teasdale et al., 2007; Gadermaier et al., 2012; Chapter 2) that may make organic management suitable for Palouse agroecosystems. Research results suggest that economically profitable yields are achievable in dryland organic, reduced tillage (ORT) production systems (Miller et al., 2008), though long-term soil fertility and weed competition challenges require further research (Teasdale et al., 2007; Berner et al., 2008).

Fundamental strategies used in organic crop production align with current agricultural practices in the Palouse. For instance, diversifying crop rotations aids the success of no-till practices by increasing nutrient cycling (Grant et al., 2002), and decreasing weed and pest infestations (Schillinger et al., 2003). Likewise, building diversity into rotations is an important management tool in organic farming (Wortman et al., 2011). Furthermore, soil pH in Palouse arable soils has been on the decline for several decades, and by the mid 1990's, was reaching levels likely to diminish crop yields in 20% of surveyed fields in north Idaho (Mahler, 2002). Soil acidification continues to be a concern in the surface soil horizons of no-till arable lands (McCool et al., 2001; Brown et al., 2008). Compared to systems that use mineral fertilizers, organic systems that receive manures and plant-based compost fertilizers experience increased soil organic matter content and, in some instances, subsequently more stable soil pH (Fließbach et al., 2007). Additionally, increased soil biological activity and soil carbon that is often observed in organic farming systems may be beneficial to long term soil health (Birkhofer et al., 2008). Though few examples of long-term organic production in the Palouse exist, the effect on soil health has been generally positive and yields can be economically competitive with conventional systems (Reganold, 1988). Incorporating organic farming methods into conventional practices also has the potential to improve the ecological impact of conventional farming (Pimentel et al., 2005). Introducing ORT methods to Palouse agricultural systems could instigate positive impacts to soil health in this region. However, the risk associated with adopting alternative practices may limit certified organic, reduced-till practices to a small niche in the larger industry.

3.1.1 Organic agriculture acreage in the Palouse

Certified organic acreage accounted for less than 1% of total crop acreage in the U.S. in 2008, despite rapid growth through the past decade (Greene et al., 2010), and similarly represents a small portion of Palouse production. Together, ID, OR, and WA organic grain acreage accounts for 6% of the U.S. total organic grain and 6% of total organic wheat acreage (USDA-ERS, 2013a). In 2011, organic grain crop acreage was 16,200 in WA, 26,500 in OR, and 26,800 in ID. This ranked ID fifteenth, OR sixteenth and WA twentieth out of 42 U.S. states that report organic grain crop acreage (USDA-ERS, 2013a). For organic wheat production, ID ranked eleventh at 9,600 acres, WA fifteenth at 5,800 acres, and OR seventeenth at 4,100 acres in 2011 (USDA-ERS, 2013a). Interestingly, neighboring Montana has the highest organic wheat acreage by state, at 55,000 acres (USDA-ERS, 2013a). Idaho also contains the largest amount of organic barley acreage at approximately 12,300 acres, while OR was second at 10,700 acres, and WA thirteenth at 800 acres. Organic and non-organic triticale is also grown, but constitutes a smaller percentage of production than wheat and barley (USDA-ERS, 2013a; USDA-NASS, 2014a; b). Considering that non-organic wheat production in ID and WA combined accounts for approximately 3 million cropland acres, organic grain and forage production is a marginal component of the regional agricultural industry (USDA-NASS, 2014a; b).

Dryland forage represents a larger portion of total organic acreage than grains in ID, WA and OR. In 2011, organic forage was grown on 76,700 acres in OR, 50,400 acres in ID, and 19,000 acres in WA. Of these organic forage acres, alfalfa constitutes 17% of total forage acres in WA, 27% in OR, and 77% in ID (USDA-ERS, 2013a). In 2011, Idaho ranked first in organic alfalfa production acreage in the U.S., producing 38,679 acres, which equates to 20% of the U.S. total. Oregon was second, producing 8% of U.S. total (20,930 acres), and Washington was nineteenth, producing 1.3% of the total (3,298 acres)(USDA-ERS, 2013a). However, in Idaho the majority of alfalfa production (including organic and non-organic) occurs in the southwest and southeastern regions of the state. For instance, in 2010, total alfalfa acreage was 62,000 (5%) in the northern district that encompasses the Palouse, compared to 1,068,000 acres (95%) in the southern districts combined (USDA-NASS, 2011).

3.1.2 Overcoming barriers to ORT management

Certainly, there are agronomic and economic challenges to sustainable, dryland ORT cropping systems. The three-year transition period to obtain organic certification is an initial hurdle (Osteen et al., 2012). During this period crops must be grown without mineral fertilizers or chemical pesticides, but are not eligible for organic price premiums (USDA-NOP, 2013). To ameliorate the challenges during the transition period, crop rotations that are competitive with weeds and that help build soil nutrients can minimize losses and produce higher yields in the early years of certified production (Borrelli et al., 2012). Researchers and farmers commonly cite weed management in organic systems as a challenge to production (Stockdale et al., 2001; Peigné et al., 2007; Goldberger et al., 2010) or a barrier to trying it (Jones et al., 2006). Growing competitive crops and utilizing shallow tillage are methods that help achieve higher ORT yields (Gallagher et al., 2010). Boyd and Brennan (2006) found that timely and repeated rotary hoe passes can reduce weed density in a cover crop by approximately 50% to 70% in a given year, though the efficacy is dependent on weather. Early spring rotary hoe treatments also reduce weed pressure in spring wheat similar to that achieved by more competitive winter wheat crops (Gallagher et al., 2010).

Grain quality can be a concern under organic production, but adequate protein levels are attainable when additional nitrogen fertilizer sources are utilized (Fuerst et al., 2011; Park et al., 2011). Fertilizer applications are often necessary to maintain profitable yields (Pimentel et al., 2005). Organic fertilizer (manure-based) is available in the Palouse, though access is not widespread (Gallagher et al., 2010). To avoid the challenge of meeting high protein requirements, varieties that have lower end-use protein needs can be substituted. For instance, organic soft white winter wheat with lower protein content (i.e. grown with low fertility input) is desirable and can correlate to greater cake volume (Fuerst et al., 2011). While there are challenges to ORT management, they are not insurmountable due to the progress many researchers and producers have made in the past decade (Mader, 2011).

3.1.3 Profitability factors of organic agriculture

Factors that determine profitability in organic production range considerably over time, and among different cropping systems and management practices. Yields in organic systems may equal those reported for conventionally managed systems (Pimentel et al., 2005; Miller et al., 2008; Wortman et al., 2011), however, a 10% to 30% yield reduction is typical (Stockdale et al., 2001; Birkhofer et al., 2008; de Ponti et al., 2012). Yields in organic systems may also be more variable than in conventional systems due to insufficient nitrogen input, weed competition, diseases and pests, and more restricted tools and resources to address these obstacles (Stockdale et al., 2001). Additionally, fewer resources have been put into developing plant varieties that are adapted to organic management (Stockdale et al., 2001; Murphy et al., 2007).

Lower yields and more variable yields indicate that price premiums are extremely important in determining profitability. Price premiums, however, are also variable and depend on factors such as differences in production costs for organic and conventional crops, and supply and demand fluctuations (Painter et al., 2007). Organic price premium fluctuations vary between crops and through time. Annual spring wheat premiums ranged from approximately 150% to 200% of conventional prices from 1996 to– 2006, and were less volatile than premiums for corn and soy (Dimitri and Oberholtzer, 2009). When price premiums are high, organic systems can match profitability of even high yielding non-organic systems (Smith et al., 2004; Pimentel et al., 2005). Fifty-nine percent of Idaho organic producers responding to a survey cited “obtaining organic price premiums” and “unstable organic prices” as challenges (Goldberger et al., 2010).

Lower input costs in organic management can increase profitability (McBride et al., 2012), though this is not always the case. In a comparison of organic and conventional wheat production systems in the major U.S. wheat producing states, average total costs for organic systems were reported to be \$12 ac^{-1} lower, and average operating costs were \$30 ac^{-1} lower (McBride et al., 2012). However, other studies report organic system operating costs that equal or exceed non-organic systems (Archer et al., 2007).

This variability highlights the need to analyze the factors that determine profitability within any given alternative cropping system to assess risk and feasibility on an individual basis.

3.1.4 Demand for organic dryland crops

The organic industry is a small component of the U.S. food supply, but it is a growing market (Greene et al., 2009). Organic production has quintupled since 1997, reaching $21.1 billion in 2008, and demand has outpaced supply (Greene et al., 2009). Reasons for the lag in supply despite consistent high demand is not entirely clear (Dimitri and Oberholtzer, 2009). Organic market research and resources have been expanded since the 2008 Farm Bill allocated funding to this effort, though gaps in organic market data still exist (Dimitri and Oberholtzer, 2009). Demand for organic grain crops specifically has grown nationally, largely driven by the need for organic animal feed to support the rapidly growing organic meat and dairy industries, but the organic grain crop supply has been slow to respond (Dimitri and Oberholtzer, 2009). Similar to national trends, current information regarding markets for organic dryland crops in the Pacific Northwest is limited. Organic grain crop production in the Palouse appears to continue to be restricted by access to these markets and a perceived regional lack of demand. Approximately 65% of Idaho organic producers report "limited demand for organic products" as a challenge, though this perception varies throughout the state (Goldberger et al., 2010).

3.1.5 Supply and market limitations

Periodic lags in organic supply are often attributed to perceived risks, including financial and those associated with transitioning to organic management (Dimitri and Oberholtzer, 2009; Greene et al., 2009). Indeed, more than half of WA non-organic wheat producers cite agronomic challenges, such as weed control and low yield potential, as the main reasons for not producing organic crops (Jones et al., 2006). Limited infrastructure is also a challenge, as demonstrated by the sparse distribution of organic "handlers"—organizations and business that are involved with the transactions that move organic crops from field to market (Greene et al., 2009). Though 41% of total U.S. processing facilities are located in states that border the Pacific Coast, (Greene et al., 2009), 36% of non-organic Washington wheat growers indicated in a survey that "[limited] transportation and access to organic buyers" was a main reason for not growing organic crops (Jones et al., 2006). Additionally, 58% of Idaho organic crop producers consider distribution limitations to be at least a moderate challenge (Goldberger et al., 2010).

At the national scale organic grain production is limited by few organic marketing outlets and the need for on-farm storage (Osteen et al., 2012). Challenges to organic grain storage and distribution are partly due to USDA standards for certified organic products, which mandate separation of organic crops from non-organic crops throughout all stages of storage and processing (USDA-NOP, 2013). Grain elevators in the Palouse are not set up to store or handle organic crops because of the separation requirements and the current low volume of organic production (personal communication, Sam White, Pacific Northwest Growers Cooperative). Lack of local storage is a barrier to adopting organic practices and can increase the transportation distance from farm to buyer. Organic crops are typically transported by truck, which is more expensive than train and barge options used for most non-organic crop commodities (Painter et al., 2007). For example, transporting organic wheat 200 miles could cost $780 for a 40-ton load ($3.90 per mile), or about $0.59 bu^{-1} of wheat (USDA-AMS, 2014a) (see Table 5), compared to transportation to local grain elevators used for non-organic commodity crops, estimated at $0.09 bu^{-1} (assuming trucking costs of $7.29 ac^{-1}, and 80 bu wheat ac^{-1}, See Table 6). Further analysis of regional infrastructure is necessary to clarify market and infrastructure limitations.

With organic production, the responsibility of market research and price negotiation is typically transferred to the grower because organic crops are inherently separate from the mainstream agricultural commodity marketing system. Several avenues exist for selling organic crops, including direct sale of raw grain for organic feed use, or value-added products if on-farm milling is a feasible option, and contracting with the few grain mills that process organic crops. Mills in the Northwest that sell and process organic crops are sparse. Contracts with mills may include transportation from the farm, or require growers to transport the product to a local elevator or to the mill itself. Marketing organic crops requires additional management compared to selling conventional crops, as growers may have to develop new markets for their products or haul their products long distances rather than simply using the local marketing infrastructure. Growers interested in producing organic crops may confront regional barriers to marketing. A better understanding of marketing supply chains will help growers reduce risk and increase returns from organic production (USDA-ARS, 2011).

3.1.6 Organic price trends

Organic wheat and barley prices fluctuated from 2010 to 2014, though they were consistently higher than conventional prices (USDA-AMS and USDA-ERS Grain and Feed Stuffs reports). Prices for food grade soft white wheat and feed grade hard red spring wheat varieties ranged between \$13 and \$15 per bushel during this period. A recent spike in price for food grade organic hard red spring wheat of \$18 to \$20 per bushel in early 2014 is indicative of these sporadic high prices (AMS Grain and Food stuff reports). Organic food grade barley prices were at a low of \$5 per bu in 2010, and have ranged from \$8 to \$11 per bu between 2011 and 2014 (USDA-AMS, 2014b).

Organic forage crops have high potential value, but a lack of livestock (or other substantially large end markets within close proximity) in the Palouse region is a limiting factor. Idaho organic alfalfa prices averaged approximately \$260 ton^{-1} in 2013 and through the first quarter of 2014 (USDA-AMS, 2014b). Organic alfalfa-orchardgrass mix forage may be similarly high value, considering organic alfalfa-orchardgrass from central OR was advertised for \$286 per large bale in May 2014 ("Capital Press," 2014). However, more robust price data are needed to provide reliable estimates of price premiums for organic forage crops in this region.

3.2 Budget analysis

Given the challenges and complexities of organic production and market access, one risk-reducing strategy would be to convert a small portion of land to organic production within a larger traditional, conventional dryland crop production system. For this reason, this study considers organic production under the premise of inclusion in a larger conventional operation. Four organic, reduced-till cropping systems (CS1, CS2, CS3, CS4) are analyzed and presented under this assumption. Two conventional cropping systems (CS5, CS6) are also discussed for comparison purposes. Enterprise budgets for individual crops within each rotation are listed in Appendix B.

Machine operations, input costs, and expected yield of these cropping systems are based on data from cropping system trial plots located in Pullman, WA. The cropping systems discussed were in place for six years, but the plots have been organically managed for ten years. Per acre data are extrapolated from small (30 ft by 50 ft) trial plot results. Adjustments and considerations were made for implementation at a commercial production scale and use input costs for the 2013-2014 season. This included the use of equipment appropriate for commercial production (in place of plot sized machinery), and adjusting yields for dockage (yield deductions based on grain kernel quality and other debris).

Profitability of the organic cropping systems is examined under three different market scenarios, based on the availability of organic price premiums, and two machinery ownership scenarios. The machinery ownership scenarios include an option of owning baling equipment (Ownership Scenario) compared to hiring custom baling services (Custom Scenario) for cropping systems that include forage crops (CS1, CS2, CS4, CS5). The option to own baling equipment is more probable for a farm operation that uses swathing and baling equipment for non-organic forage crops or grain straw residue. Hiring custom baling services would be more likely for farm operations that do not produce any non-organic straw or forage products. The net present value (NPV) of returns over variable costs (VC) and total costs (TC) of these two scenarios are analyzed under three market scenarios: 100%, 50% or 0% of crop yields sold with organic price premiums. This strategy allows us to examine the impacts of potential fluctuations in organic market prices and associated risks by cropping system. The NPV of each system was multiplied by standard amortization factors for an 8% interest rate and the number of years in the crop rotation in order to generate an annual equivalent NPV (AENPV) that allows comparison across systems with different lengths. Overall, this economic analysis projects the productive capacity of ORT cropping systems that can be achieved in the mid-term, after some of the challenges of transition and early production have been overcome, under six combinations of market and production scenarios. The AENPV of CS6 will be used as a proxy to determine if using an ORT cropping system would result in sustained lower profitability than if the land had remained under conventional production.

Cropping system analysis will consider profitability as well as agronomic suitability. The two-year rotations (CS2 and CS3) were designed to address specific weed and fertility objectives, and will be analyzed for success in meeting these objectives. However, they both include winter crops only, and research from the past several decades supports that rotations including both winter and spring crops are more advisable for this region (Schillinger et al., 2006). The common three-year conventional rotation of winter wheat, spring wheat or barley, and a grain legume helps disrupt weed, insect, and disease cycles, which have helped the adoption of reduced-tillage practices in non-organic systems (Schillinger et al., 2006). Thus, the findings of these 2-year systems can be viewed as interim strategies to be incorporated into other crop rotations, but are not suggested as long-term cropping systems, *per se*. CS1 and CS4, which include both winter- and spring-seeded crops, will be analyzed for their potential as more long-term ORT cropping systems. Economic components including cash flow are discussed below for these six cropping systems.

3.2.1 Study area

These enterprise budgets are for dryland organic cropping systems in the eastern region of the Palouse, including eastern Washington and the Northern panhandle area of Idaho. The climate is Mediterranean with cool wet winters and warm dry summers. Average annual precipitation is approximately 24 inches, with 70% or more occurring in winter months between November and March (Kok et al., 2009). The cropping systems were distributed in replicated plots (30 x 50 ft, 5 replicates of each cropping system) across a uniform 5% south-facing slope. The soil type was uniformly Palouse silt loam throughout the plots.

3.3 Crop rotation: Overview

A few common elements were used throughout the ORT cropping systems in this study. Perennial and annual winter legume-hay crops were included because of their soil nitrogen fixation benefits and ability to help suppress weeds (Borrelli et al., 2012). Because winter wheat is often the principle income source for dryland farmers in the Palouse (Schillinger et al., 2003), it generally follows legume-forages in rotation to take advantage of nitrogen inputs, reduced disease incidence, improved soil structure, and greater residual soil moisture that can result from legume crops (Peoples et al., 2009). Winter crops in general are important in rotations because they are more competitive against weeds than spring crops in organic systems (Gallagher et al., 2010). However, raising both winter and spring crops in rotation improves weed control because the differences in their associated management regimes changes conditions that affect weed species (Liebman and Davis, 1999). Murphy et al. (2006) showed that under no-till, diverse 3-year rotations, weed density decreased from 41,000 to 8,000 seeds m^{-3} over 6 years. In the Palouse, reduced-till rotations of winter wheat, spring barley, and peas have shown the greatest weed suppression and economic stability compared to shorter, less diverse rotations (Young et al., 1994).

Cultural practices that accompany crops in rotation are important for the effect each crop phase imparts on the system. For instance, the production of forage/hay crops with multiple cuttings for hay and/or repeated mowing throughout the growing season helps deplete weed seed banks and reduce weed pressure (Peigné et al., 2007; Gallagher et al., 2010). Including shallow tillage treatments during early crop growth stages and post-harvest mowing were practices used in the current study for minimizing weed infestations (Table 3.1). These principles are fundamental components of the ORT cropping systems in this study, described in more detail below.

3.3.1 Cropping System 1—Organic 5-year rotation: Perennial alfalfa-orchardgrass/winter wheat/spring barley

Cropping system 1 (CS1) receives minimal inputs in four out of the five years of the rotation, including three years of a perennial alfalfa-orchardgrass mix, followed by one year of winter wheat. Manure was applied during organic grain production in one or two years immediately preceding the beginning of this rotation. An alfalfa-orchardgrass mix stand was grown instead of a pure alfalfa stand because grass improves early stand establishment through better weed competitiveness, while the alfalfa is slower to establish (Fuerst et al., 2009). Winter wheat received no manure fertilizer inputs, and thus relies on nitrogen fixed by the alfalfa stand and any residual nutrients from manure applied prior to the ley crop phase. Spring barley that follows winter wheat received 1 ton ac^{-1} of poultry manure (See Table 3.1 for agronomic calendar and inputs, and Appendix A for machine operations).

3.3.2 Cropping System 2—Organic 2-year rotation for weed control: Winter triticale/winter pea

Cropping System 2 (CS2) was implemented to determine if it was possible to maintain profitability while addressing a perennial weed infestation (bindweed). This rotation included winter triticale, a cross between wheat and rye, grown for grain, followed by winter pea hay. Winter triticale is not widely grown in the Palouse, but is high yielding and competitive against weeds (USDA-ARS, 2011). Winter pea hay provides revenue and additional weed control through repetitive mowing during the growing season. Poultry manure (2 ton ac^{-1}) was applied at the time of winter triticale seeding to support crop competitiveness.

3.3.3 Cropping System 3—Organic 2-year rotation with green manure: Winter pea green manure/winter wheat

To assess the ability of a green manure to supply nutrients and improve soil quality, a winter pea green manure crop was grown in rotation with winter wheat (CS3). This system uses no manure inputs and requires no haying operation, but forgoes revenue in alternating years in order to grow the green manure crop. The green manure is mowed, not plowed, though some incorporation into the soil occurs through rotary hoeing and harrowing. The success of this system relies exclusively on the winter wheat crop receiving nitrogen, other nutrients, and weed suppression from the winter pea green manure.

3.3.4 Cropping system 4—Organic 3-year: Spring wheat/winter pea hay/winter wheat

Cropping system 4 (CS4) is grain-intensive, following a spring wheat, winter pea hay, winter wheat progression. It is similar to typical rotations used in non-organic Palouse agricultural systems, except for the substitution of a legume-forage for a spring legume crop (typically lentils, peas or garbanzos). Winter wheat and spring wheat crops both received approximately 2.1 ton ac^{-1} of poultry manure at seeding time. With the inclusion of winter pea hay, this system received some form of organic nitrogen input in each phase of the rotation.

3.3.5 Cropping system 5—Conventional 3-year with forage: Spring wheat/winter pea hay/winter wheat

This rotation is intended to be a non-organic comparison to CS4. However, due to low yields of the winter pea hay, the CS6 crop rotation will be used as an economic comparison to CS4, as it represents a more realistic commercial scale crop rotation. Unless winter pea hay yields could be improved, growers would be unlikely to include this crop in conventional rotations. An economic analysis for this system is included in the results section in order to provide a conventional example of winter pea hay production, but this system is excluded from the comparison of cropping systems. Furthermore, only the winter pea hay crop budget reflects the results of the research trials. Winter and spring wheat yields were below average for non-organic production in the Palouse, thus these budgets are based on 2013 University of Idaho Extension enterprise budgets for direct seed production in this area (Painter and Donlon, 2013), as described in the following section.

3.3.6 Cropping system 6—Conventional 3-year, no forage: Spring wheat/spring pea/winter wheat

Cropping system 6 (CS6) is a non-organic crop rotation of spring wheat – spring pea – winter wheat cash crops managed with direct-seed practices common in the Palouse. CS6 was intended as an economic comparison to the organic systems, but similar to CS5, yields from the research trial for CS6 were below average for conventional systems in this region. Therefore, the economic analyses for these three crops—including yields, machine operations, fertility, and pesticide inputs—are based on more typical non-organic inputs and outcomes from the 2013 direct seed budgets for Northern Idaho (Painter and Donlon, 2013) and do not reflect the results of the research trial plots.

3.4 Budget assumptions

Input costs for fuel, seed, fertility, labor, land, overhead, operating interest, organic certification, and custom rates for machinery services such as baling hay are listed in Table 3.2 and described below. Additional costs associated with pesticides are listed in Table 3.3.

3.4.1 Farm size

These enterprise budgets assume a 100-acre certified organic section of a 2,000-acre farm (5% of operation is organic). This approach reduces the risk of using an alternative cropping system while also achieving economies of scale with respect to farm machinery costs. Certified organic production on 100 acres represents both a value-added strategy and a way to increase diversity within a larger commercial farm. Machinery costs are shared between organic and conventional crop production, with acknowledgement of the need to separate organic and non-organic materials to avoid contamination.

3.4.2 Yield

Yields presented here represent average production capacity between years 7 to 11 of the Boyd farm ORT cropping system trials, following six years of experimental organic management and soil building practices. Grain yields are adjusted for dockage, a deduction percentage applied to total yield based on quality standards, as would be applied by regional grain elevators. Crop failures due to a weed infestation during year six of the experiment (2008) were excluded from average calculations, except for alfalfa establishment year plots (CS1-YR1). Yields represent the average of 3 to 5 years of data depending on the number of crops in rotation. In some instances fewer years of yield data were available due to the substitution of a different crop in that phase of the rotation (i.e., spring barley for spring wheat). Crop failures that occurred after 2008 are included in average yields, with the exceptions of spring barley yield reported in CS1, which represents only one year of data (2013), and winter pea hay in CS5, which represents the average of 2 years of data. Additionally, it is important to consider yield potential within the context of crop rotation to account for rotational effects of preceding crops.

3.4.3 Crop prices

Grain crop prices listed in the budget are farmgate prices based on estimates from regional mills that are comparable to national and regional averages as reported by USDA-AMS and USDA-ERS reports (Table 3.4) (USDA-AMS, 2014b; USDA-ERS, 2014c). Farmgate prices represent the net price received by growers after marketing costs have been paid, such as costs of transporting crops to market. Assuming organic crops may be sold under multiple arrangements, an additional 1,000 miles per year of tandem-axle truck use is included in machine operation costs to account for extra transportation that may be required for organic crops. Based on the 500 bu tandem-axle truck in the machinery complement, and an estimated 80 bu ac^{-1} yield equating to 6 acres per truckload, this estimate represents multiple scenarios per load, including transporting production from 35 acres of wheat approximately 165 miles, or a 20-mile roundtrip for 50 acres of production. In the event that further transportation to market is required, estimated costs for transportation of crops to market are provided in Table 3.5.

Forage prices are based on regional averages (USDA-ERS, 2014c; USDA-AMS, 2014b). Average organic price per ton for large bales (3' x 4') was used to determine hay prices for several reasons. Organic price data were more abundant for large bales than for small bales (16" x 18" x 48") (USDA-AMS, 2014b), and since small bales are typically more expensive, this approach provides a conservative price estimate. This average price is thus on the low end for small bale production assumed in the two scenarios of owning equipment or custom hiring. The alfalfa-orchardgrass forage is estimated at \$215 ton^{-1} in this budget; few sources of organic alfalfa-grass mixes were available for this region during this time period. This estimate is based on 2013 average non-organic "Premium/Supreme" quality and organic "Supreme" to "Good" pure alfalfa prices (USDA-AMS, 2014b). It is a low estimate considering average organic alfalfa prices in Idaho were \$260 ton^{-1} in 2013-14 (USDA-AMS, 2014b), and one example of large square organic alfalfa-orchardgrass advertised for \$286 ton^{-1} ("Capital Press," 2014) as mentioned earlier. For scenarios when organic prices are not available, 2013 – 2014 average non-organic, "Good" to "Fair" quality alfalfa prices are used. No regional winter pea hay prices are available, therefore, organic winter pea hay prices are based on estimates for "Good"/"Premium" quality non-organic alfalfa hay prices in WA and ID (USDA-AMS, 2014b), as winter pea is a high quality forage similar to alfalfa. Conventional prices for winter pea hay are based on average prices for "Good" – "Fair" quality rated alfalfa for 2013 – 2014 (USDA-AMS, 2014b).

3.4.4 Labor costs and input

Labor is valued at $20 per hour throughout, slightly higher than 2013 labor costs for equipment operation estimate of $17.80 per hour used in University of Idaho Extension bulletins (Patterson and Painter, 2013). Wages rates are higher in Washington State than in Idaho, e.g., in 2014 WA's minimum wage was $9.32 per hour, compared to $7.25 in Idaho. Specific additional hours required for organic crops are distributed among administrative time necessary for the certification process and under management fees to account for extra field monitoring and other operations. It is important to note that labor costs can represent an "opportunity cost" for owner-operators, who may not be paying themselves but who are missing the opportunity to work elsewhere, or it can be represented by actual cash wages, or some combination of the two.

3.4.5 Land costs

Land rent is calculated based on a 25% crop-share agreement. While cash rent is also very common, the traditional risk-reducing strategy of a crop-share agreement shares production and price risk factors between the operator and the landowner and is an appropriate proxy for land rent in this somewhat risky alternative enterprise. It is assumed that the landlord receives 25% of the crop value and is not responsible for any operating costs associated with crop production.

3.4.6 Fertilizer costs

Organic fertilizer is assumed to be poultry manure, sourced from regional suppliers. To account for limited suppliers in the Palouse regions, transportation costs for 150 miles from source to farm are assumed. The distances from two different regional manure sources to Pullman, WA, are approximately 150 miles each, which represents the longest likely distance from fertilizer source to farm within the Palouse region. Cost for manure fertilizer is estimated at $18 per ton, and hauling costs at $25 per ton, based on quotes from regional sources (Cascade Agronomics, LLC, and Oakdell Egg Farms Inc). Fertilizer costs in this budget do not include application. A manure spreader is included in the on-farm machinery complement, which is less expensive (\$2.40 ac^{-1} compared to \$11 ac^{-1}) if also used on other non-organic acreage, and may cause less compaction than commercial application (See Appendix A).

3.4.7 Seed price and rate

Seed prices represent 2012-2013 crop year values. Seeding rates for organic crops are based on practices from the research trial plots. Increased seeding rates are used in organic production because thicker stand density helps crops outcompete weeds. Non-organic seed prices are 2013 values (Patterson and Painter, 2013), and rates are based on regional practices (Painter and Donlon, 2013).

3.4.8 Machinery costs

Machinery costs assume the equipment used in organic production is also used for the remaining 1,900-acre conventional farm that uses conservation tillage practices. Machinery used for forage harvesting may be an exception, however, as not all non-organic farms have swathing and baling machinery. Thus, the scenario of owning this equipment (Ownership) is compared to custom baling (Custom) for forage crops, as described in the Budget Analysis section. Baling equipment for small square bales was used in the machinery complement, reflective of older equipment that would likely be owned by an individual farm. Machinery that would be owned by the non-organic farm operation with a small percentage of organic production is described in Table 3.6. Machine operations for each cropping system are detailed in Appendix A.

3.4.9 Custom baling rates

Given the relatively small acreage that would be allocated to hay production, custom baling would be a practical option. Costs of crop systems that include hay production were also analyzed with custom baling costs for small bales (Custom scenario, for rates see Table 3.2). Since custom haying services typically have a minimum charge per acre, if yields were below 1 ton ac^{-1} the 1-ton price was used, which corresponds to a minimum price. If hay yields are very low, it may not be profitable to harvest the crop, depending on current hay prices.

3.4.10 Organic certification costs

Certification costs vary by state in price and structure. They are applied on a sliding scale based on gross income from the previous year's production. The base fee in Idaho is $125 per year if gross farm income from organic production is under $15,000, or $200 per year if the value of organic production is over $15,000. Additional fees are applied on a sliding scale ranging from $10 to $5,000 per farm depending on gross sales, plus $35 per hour for a certification agent's time for annual inspection (ISDA, 2006). The initial certification fee in Washington is $425 per year, plus an additional fee based on gross sales in the first year of production. Washington fees in successive years range from $200 to $3,000 annually per farm. The initial certification fee may be higher than fees in successive years for projected gross annual income <$40,000 (WSDA, 2013). We assume an average annual certification fee of $400 for certification of 100 acres in these budgets, although this value would change from initial to successive years of certified organic production, and by yield and value of the crops grown.

Additional administrative time required for the certification process is assumed to be one hour per acre and is itemized under certification costs in the budgets. Farm operations that have been certified for 10 or more years report an average of 81 hours per year, or 2.5 hours per acre, for organic wheat certification (McBride et al., 2012). Correspondingly, this would represent a production size closer to approximately 30 acres, about one-third the size of the organic operation assumed in this budget. Administrative time per acre would likely decrease with increasing acreage. This budget assumes one hour per acre for administrative costs associated with organic production, which is higher than the estimate provided by a regional organic wheat grower.

3.4.11 Management fee

A flat rate of $20 per hour is used to calculate management fees for organic and non-organic cropping systems. Conventional management fees are calculated as 5% of gross revenue, and are based on fee rates from the 2013 Direct Seed Budgets for Northern Idaho (Painter and Donlon, 2013) (See Table 3.7.). Management fees for organic crops were calculated as 35% higher than that of conventional, based on producer estimates (Miller et al., 2008). This reflects the additional time that is required for the hands-on management that is often necessary for organic crop production, such as scouting and addressing weed and pest problems.

3.4.12 Interest rates

An interest rate of 7% is used for both short- and long-term loans, covering annual interest costs on operating loans as well as interest costs for capital invested in machinery and other equipment. This interest charge represents a direct cost for capital that is borrowed and an opportunity cost for personal investment, representing the rate of return that is sacrificed by not investing equity capital elsewhere.

3.4.13 Overhead

Overhead costs were calculated as 5% of total operating costs. This is higher than the 2.5% rate typically used for non-organic production (Patterson and Painter, 2013), to reflect additional field and management requirements for organic operations.

3.4.14 Crop insurance

Crop insurance listed in the budgets is for multiple-peril coverage. Estimates were produced using the USDA Risk Management Agency quick estimate calculator (http://ewebapp.rma.usda.gov/apps/costestimator/Estimates/QuickEstimate.aspx) for the 2014 crop year. Crop insurance rates listed are for yield protection of Idaho organic dryland crops, assuming 75% coverage. Estimated approved yield, per acre premium, and per acre liability coverage, assuming 35 acres of production per crop (approximately 1/3 of 100 acres), are provided in Table 3.8.

Recent changes have been made to organic crop insurance coverage. As of the 2014 crop year, contract price options are available to organic producers that can be used for price election values when purchasing crop insurance. Thus, producers receiving a contract price can guarantee insurance coverage that reflects the actual value of their crop more closely (USDA, 2013). Furthermore, beginning in 2014, the 5% surcharge on all organic crops will be removed (USDA, 2013), improving the benefits of crop insurance for organic growers.

3.5 Cost and returns summary

3.5.1 Summary of yields

Yields from the cropping system trial plots suggest competitive potential for some crops under ORT management (Table 3.9). Yields for organic winter wheat were highest in CS4, the cropping system that received manure fertilizer (84 bu ac^{-1}, ±14), compared to CS1 (50 bu ac^{-1}, ±17) and CS3 (39 bu ac^{-1}, ±19) with no manure. CS4 winter wheat yields are similar to average winter wheat yields in Latah County, ID, from 2002 to 2012 (77 bu ac^{-1}, ±6) (USDA-NASS, 2011). Winter triticale, which was only grown in one cropping system (CS2), was the highest yielding grain crop (94 bu ac^{-1}, ±18). Organic spring wheat yields (only included in CS4) were 33 bu ac^{-1} (±15), lower than the Latah County average from 2002-2012 (55 bu ac^{-1}, ±7) (USDA-NASS, 2011). Organic spring barley demonstrates some potential as a feed grain crop, yielding 1.9 ton ac^{-1}, (±0.3) compared to Latah County average (2002 – 2011) non-organic yields of 1.5 ton ac^{-1} (±0.3).

Organic alfalfa yields for the first (CS1-YR2) 1.66 tons ac^{-1} (±0.6 tons) and second (CS1-YR3) 2.3 ton ac^{-1} (±0.7 tons) years of production were comparable to the non-organic, regional 10-year annual average (2001-2010) for Latah County (1.9 ton ac^{-1} ±0.2 tons).

Organic winter pea hay yields were higher in CS4 at 1.1 ton ac^{-1} (±0.6) than the yields for the non-organic winter pea hay (0.4 ton ac^{-1}, ±0.1). No other regional non-organic winter pea hay yields were available for comparison. Results from the research trials are in agreement with other studies that found winter wheat and alfalfa to produce competitive yields under organic farming methods (Miller et al., 2008; Fuerst et al., 2009; Wortman et al., 2011)

3.5.2 Summary of cropping system results

CS1-Organic 5-year rotation: Perennial alfalfa-orchard grass/winter wheat/spring barley

Cost of production analysis of CS1 showed a positive net present value of returns over total costs (TC), which includes amortized establishment costs of alfalfa distributed between the first and second year of production. Alfalfa-grass mix is suitable not only for the transition period to organic (Fuerst et al., 2009), but demonstrates profit potential under certified organic production in the medium-term (after the transition period, in years 10 – 15 of production)). Poor termination of the alfalfa-grass stand prior to seeding winter wheat resulted in substantial weed pressure from volunteer alfalfa, and was a likely contributor to the low winter wheat yields in this rotation. If methods for removing the alfalfa crop are improved, winter wheat yields may increase. Whether additional nitrogen input may be necessary beyond what is fixed during the alfalfa phase requires further research; any potential gains would have to be measured against additional costs of fertilizer. Spring barley with manure input demonstrated profit potential in the final year of rotation. In summary, profitability of CS4 is attributable to the high value of alfalfa and lower input costs despite low winter wheat yields relative to the other cropping systems.

CS2: Organic 2-year rotation—The value of winter triticale

The profitability of CS2 is a result of high winter triticale yields, equaling or exceeding organic winter wheat, and high organic price premiums for this crop. While CS2 appears to have the highest returns over TC (a measure of long-run profitability), under both

Custom and Ownership scenarios when assuming 100% organic price premium, it is unprofitable if only 50% of the crop is sold with an organic price premium. While NPV of returns over variable costs (VC) are still positive given 50% organic price premiums, they are less than those of the non-organic production system (CS6). Low yields in the winter pea hay crop phase of this cropping system can be blamed on its relatively poor performance in the short run; however, the profit potential of including winter triticale in rotations is demonstrated. Given its yield potential and organic price premium, winter triticale can generate revenue from land where high weed pressure exists, and may be suitable for substitution in other ORT cropping systems. However, inclusion of winter triticale in crop rotations should be weighed against the challenges of securing a buyer for a small market crop.

CS3: Organic 2-year rotation—Low input (green manure)

Winter wheat yields were low in CS3 compared to CS1 and CS4, and were not high enough to compensate for the costs of growing the winter pea green manure crop (Table 3.9.). Despite the lack of fertilizer inputs for this system, cost of production analysis indicates a negative NPV for returns over TC. NPV of returns over VC for CS3 were positive under 100% and 50% organic premium availability, but lower than the NPV of returns over VC for CS6. This rotation would not be economically sustainable in the long term because returns over TC were negative under all scenarios. Additional fertilizer input beyond the use of green manure is necessary for profitability in these ORT cropping systems, at least in the medium term (years 10 – 15 of production).

CS4: Organic 3-year rotation—Grain intensive

This rotation demonstrated the greatest profit potential over total costs, and will be discussed further below. The success of this system suggests the importance of including manure inputs and legume crops to meet soil fertility needs (Watson et al., 2002), particularly for grain production (Fredriksson et al., 1998), and the benefits to weed control of including crops with different planting dates and growth periods (i.e., spring wheat) in crop rotation (Liebman and Davis, 1999). In Palouse non-organic systems, 3-

year rotations that include spring wheat in combination with winter wheat and grain legumes show higher yields due to greater pest suppression (Schillinger et al., 2006). Agronomic highlights of this system include winter wheat production in high yielding years exceeding 90 bu ac^{-1}, which is competitive with the non-organic comparison trial plots and demonstrates production capacity similar to average regional yields of 90 to 100 bu ac^{-1} (Schillinger et al., 2003). Also, winter pea hay in this system was higher yielding than in the conventional plots. Visual assessment suggested this might be a result of greater weed density in the organic plots, providing protection from wind and early spring frost for the young hay crop (Dennis Pittman, personal communication, 2013).

CS6: Conventional 3-year rotation—No forage: Spring wheat/spring pea/winter wheat

CS6 represents average non-organic production capacity and practices in the Palouse, and thus is used for comparison with the organic cropping systems. Given average wheat prices and yield, CS6 is less profitable than CS1, CS2, and CS4 when organic price premiums are available. However, when organic price premiums are not available for 100% of production, this typical non-organic Palouse system is more profitable.

3.5.3 Ownership of forage harvest equipment vs. custom hiring

Comparing the scenario of owning forage machinery versus custom hiring shows that the Ownership Scenario (OS) leads to greater returns than the Custom Scenario (CS), though CS is still profitable. Machine costs are lower for OS than costs under CS, as would be expected, as custom operators need a profit margin in order to operate in the long run (Fig. 3.3). In both CS and OS, NPV of returns over TC and VC in CS1, CS2, and CS4 are greater than for CS6 when organic price premiums are available for 100% of yields (Fig. 3.1, 3.2). NPV of returns over TC from CS1 are \$8 ac^{-1} higher under OS compared to CS, and \$21 ac^{-1} higher in CS4 under OS compared to CS, assuming 100% organic price premiums. If only 50% of crop yields are sold with organic price premiums, NPV of returns over TC are negative for all organic cropping systems under

Ownership and Custom scenarios, though CS4 shows the least amount of loss (Figure 1 and 2). Under both CS and OS, NPV of returns over VC in CS1 and CS4 are higher than CS6 at 50% price premium availability. Furthermore, CS1 and CS4 NPV of returns over VC remain positive under market conditions where no organic price premium is available in both production scenarios, though they are less profitable than CS6.

Cropping systems that include a forage crop (CS1) benefit more from OS, in which forage harvesting equipment is owned rather than custom hired, than does a more grain intensive system (CS4). Assuming 100% organic price premiums, CS1 AENPV of returns over VC are \$22 ac^{-1} higher under OS than under CS; in CS4, returns are \$12 ac^{-1} higher under OS than for CS. The greater difference in returns over VC between OS and CS for CS1 arise from the use of forage equipment in 3 out of 5 years in the rotation. Thus, a farm operation that includes a greater percentage of high-value forage production (such as alfalfa in CS1) may benefit more from owning forage equipment than would more grain-intensive systems (CS4). Recall that OS assumes forage equipment is used in other aspects of farm operation beyond the 100 acres of organic production. Furthermore, incorporating organic production may be more profitable in a more diversified farm system that may already include some type of forage production. In a less diversified farm system, however, custom hiring for forage harvest operations is still a profitable option.

3.5.4 Total costs and variable costs

Cropping system average variable costs per acre were highest in CS4 at \$236 per acre, followed by CS6 (\$220 ac^{-1}) and CS1 (\$171 ac^{-1}). Similarly, cropping system average total costs were higher in the organic systems (CS1 and CS4) than in the conventional comparison (CS6). Comparing the winter wheat phase only across all cropping systems, total costs of production were highest in organic systems CS3 (\$682 ac^{-1}) and CS4 (\$565 ac^{-1}), however TC of winter wheat in CS1 (\$358 ac^{-1}) were lower than in conventional system CS6 (\$438 ac^{-1}). Per acre variable costs of winter wheat were lower for all organic cropping systems, ranging from \$121 to \$211, relative to the conventional system (\$245 ac^{-1}) (Table 3.9). Higher variable costs in the organic systems also corresponded to higher yields, largely due to costs of manure inputs and possibly differences in weed pressure. Results from the 2009 Agricultural Resource Management Survey (ARMS) found both average total costs and variable costs of production for non-organic wheat to be higher than for organic wheat, with total costs for non-organic wheat at \$263 per acre compared to \$251 per acre for organic wheat, and variable costs of \$113 per acre for non-organic wheat compared to \$83 per acre for organic wheat (USDA-ERS, 2013b). However, wheat yields also tended to be lower in organic systems compared to conventional in the 2009 ARMS (McBride et al., 2012).

Looking at the components of average variable costs by cropping system, machine operation and fuel costs are lower in conventional system CS6 than in organic systems CS1 and CS4 (Fig. 3.4). If both pesticide costs and machine costs are included in the comparison, costs for the non-organic system become notably higher than for the organic systems. However, additional costs in the organic systems (certification, management, higher seed costs) make up for the difference in total variable costs in the CS4 cropping system. While fertilizer costs are very low in CS1, where manure is only applied one out of five years, fertilizer costs for the organic rotations that receive fertilizer applications in 2 out of every 3 years (CS4, CS6) are similar to the conventional rotations.

3.5.5 Highest organic profit potential

Cost of production analysis indicates that CS1 and CS4 show the most potential for profitability under a range of organic price premium scenarios, and thus the ability to withstand moderate market fluctuations. The success of these two cropping systems speaks to the economic resilience that can result from longer crop rotations that include a combination of spring crops, winter crops, and forage. Excluding CS2, CS4 has the highest NPV over TC (\$350 ac^{-1}) under the maximum profit scenario of OS for machinery + 100% organic price premium followed by CS1 (\$169 ac^{-1}), then CS6 (\$79 ac^{-1}) (Fig. 3.1). Both CS1 and CS4 maintain higher NPV of returns over VC than the non-organic comparison (CS6), assuming either 100% or 50% organic price premium availability. When no organic price premiums are available, CS1 and CS4 have positive NPV, though these values are lower than the NPV of CS6. For a farm operation without hay or forage production machinery, CS4 shows the highest profit and most resilience to organic price fluctuations. For a farm operation that already produces non-organic forage products, CS1 may be the most profitable, particularly when organic alfalfa prices are higher than the estimates used in this analysis.

3.5.6 Breakeven analysis and revenue contributions by crop in rotation

Comparing expected yield (price) to total and variable costs demonstrates breakeven prices (yields) for crops in CS1, CS4, and CS6 (Fig. 3.5), given 100% availability of organic price premiums. A management fee is included in total costs; therefore, returns above the breakeven point for covering total costs show returns to risk (profit). CS1 is profitable in 3 out of 5 crop years. Revenue exceeds variable costs for CS1-Year 2 (second year of alfalfa) by \$188 ac^{-1} and exceeds total costs for CS1-Year 3 (final year of the alfalfa rotation) by \$61 ac^{-1}. Both winter wheat and spring barley crops are profitable (years 4-5), with positive returns above total costs. Amortized costs of alfalfa establishment are included in total costs of the second and third years of the alfalfa crop, thus this system recovers all establishment costs by the end of the rotation.

CS4 is profitable in 2 out of 3 years of the rotation. In CS4-Year 1, spring wheat revenue is just above the total cost breakeven point, and thus provides returns to management plus a small additional profit (\$33 ac^{-1}). Winter pea hay revenue in CS4-Year 2 does not cover total costs (total revenue – total costs = -\$116), although variable costs are covered. However, in addition to the agronomic benefits of including a legume-forage in rotation, short-term viability of the winter pea is balanced by the long-term viability from winter wheat revenue that far exceeds total costs in CS4-Year 3 (\$527). In CS4, spring wheat shows marginal profitability and winter pea hay is viable in the short-term, but the majority of the revenue and the long-term sustainable/profit of this system is dependent on high revenue from the winter wheat phase (year 3) (See Fig 3.5).

In the conventional system CS6, profit is less volatile than in the organic systems. CS6 is profitable in 2 out of 3 years, similar to CS4. Total revenue remains slightly higher than total cost in CS6-Year 1, with positive net returns for spring wheat (\$29 ac^{-1}) and for winter wheat in CS6-Year 3 (\$89 ac^{-1}). CS6-Year 2 spring pea (grain) produced negative returns over TC (-\$16 ac^{-1}), though to a lesser degree than the organic winter pea forage in CS4. Returns to management plus additional profit are achieved in spring and winter wheat phases, with the highest additional profit earned in the winter wheat phase.

3.6 Conclusions

Organic, reduced-till farming methods are congruent with past and current soil conservation efforts in the Palouse and appear to have some potential for small-scale production. CS4, the profitable three-year organic rotation, is similar in terms of sequence and crop choice to common non-organic crop rotations currently used by Palouse farmers. The organic alfalfa-5 year rotation (CS1) also shows significant profitability, largely due to the high value of alfalfa forage, despite significantly lower winter wheat yields. Furthermore, if better alfalfa crop termination methods are developed, winter wheat yields will likely increase, and improve the overall performance of this system. Winter triticale shows potential as a high yielding organic crop, with potential high value if the market for triticale is available. Winter pea hay is a less common forage crop, though a high value one, and may be a good option for organic production if organic forage markets continue to grow. While there is inherent risk in adapting new and alternative agricultural management systems, results from this study show potential benefits for adopting organic reduced-till methods, and further experimentation at production scale is merited.

Table 3.1 Inputs and machine operations of four organic, reduced-till cropping systems and two non-organic, reduced-till cropping systems

Crop System	Crop, seed variety and rate (lb/acre), Fertilizer (unit/acre)	Machine Operation Calendar
Organic Alfalfa-wheat 5-year (CS1)	Alfalfa hay mix Ladak alfalfa (12) Potomac Orchardgrass (8)	September-October: undercutter, 2x rotary harrow March: rotary hoe April-May: undercutter, rotary hoe, undercutter, plant June: rotary hoe, mow, rotary hoe, flail mow July: swath, bale August – September: 2x flail mow
	Alfalfa (2nd yr) --	September – October: 2x rotary harrow April – May:: 3x rotary hoe June: swath and bale July: swath and bale August – September: 2x flail mow
	Alfalfa (3rd yr) --	September – October: 2x rotary harrow April-May: 3x rotary how June: swath and bale (mow if necessary for weeds) July: swath and bale August – September: flail mow or undercutter
	Winter Wheat Brundage (135)	October: undercutter, rotary harrow, plant April – May 3x rotary hoe August: harvest September: flail mow
	Spring Barley Hesk (95) 1.0 ton manure (114 lb TN, 9 lb NH^{4+})	October: undercutter, rotary harrow and plant March – April: 2X rotary hoe, 2x undercutter, rotary harrow, spread manure, plant May: rotary hoe August: harvest September: flail mow
Perennial Weed Mgmt 2-year (CS2)	Winter Triticale Trimark336 (135) 2.0 tons manure (228 lb TN, 19 lb NH^{4+})	September – October: undercutter, 2x rotary harrow, plant, spread manure April – May: 3x rotary hoe August: harvest September: flail mow
	Winter Pea hay Windham (200)	September – October: undercutter, 2x rotary harrow, plant April – May: 3x rotary hoe June: swath and bale July – September: 2x flail mow (or undercutter)
Green Manure–Wheat, 2-year (CS3)	Winter Pea Green Manure Windham (200) (no harvested crop)	September - October: Undercutter, rotary harrow, plant April – June: 4x rotary hoe June – July: 2x flail mow September: flail mow (or undercut)
	Winter Wheat Brundage (135)	September – October: Undercutter, rotary harrow, plant April – May: 3x rotary hoe August: harvest (September: flail mow if necessary)

(Table 3.1. continued)

Crop System	Crop, Seed variety and rate (lb/acre), Fertilizer (Unit/acre)	Machine Operation Calendar
Organic Grain intensive 3-year, (CS4)	HR Spring Wheat Kelse (150) 2.2 tons manure (252 lb TN, 21 lb NH^{4+})	September – October: undercutter, rotary harrow March – April: 2x hoe, undercutter, rotary harrow, plant, spread manure May: rotary hoe August - September: harvest, fail mow if necessary
	Winter Pea Hay Windham (200)	September – October: undercutter, rotary harrow, plant April – May: 3x rotary hoe June: Swath and bale July: flail mow August: undercutter
	Winter Wheat Brundage (135)	September – October: undercutter, rotary harrow, plant, spread manure April – May: 3x rotary hoe August: harvest September: flail mow, if necessary for weed control
Non-Organic, With Forage 3-year (CS5)	Dark Northern Spring Wheat (100) 130 lb N 5 lb P, 25 lb S	March: spray April: plant/fertilize May: Spray June: Aerial spray August: Harvest September: flail mow, rotary harrow, spray
	Winter Pea Hay Windham (200)	October: plant May: spray glyphosate June – July : swath, bale, spray & flail mow
	Winter Wheat Brundage (90) 110 lb N, 5 lb P, 15 lb S	September: Spray, drill/fertilize April: Spray June: aerial spray August - September: Harvest, flail mow, r. harrow, spray
Non- Organic, No forage 3-year (CS6)	Dark Northern Spring Wheat (100) 130 lb N, 5 lb P, 25 lb S	March - April: spray, plant/fertilize May: Spray June: Aerial spray August - September: Harvest, flail mow, r. harrow, spray
	Spring Pea Aragorn (200)	March: spray weeds April: plant June: Aerial spray weeds August - September: harvest, spray weeds
	Winter Wheat Brundage (90) 110 lb N, 5 lb P, 15 lb S	September: Spray, drill/fertilize April: Spray June: aerial spray August - September: Harvest, flail mow, r. harrow, spray

Note: For the Boyd crop system trials, the undercutter used was a Haybuster sweep; the rotary harrow was a 4.5 m, double pull Phoenix® (Excel Industries LLC: Phoenix Rotary Equipment, Waseca, MN); the rotary hoe was a 4.5 m M&W® 15 MT (MT= minimum tillage)(M and W Gear Co., Gibson City, IL) (Gallagher et al., 2010). Cost calculations were based on the machinery specifics as listed in the Machinery complement (Table 3.6). TN = Total N and refers to inorganic and organic forms of N applied via fertilizer.

Table 3.2 Input costs

Fuel:	Unit	Price/unit
Diesel	gal	$3.40
Gas	gal	$3.50
Seed:		
Alfalfa hay mix - Ladak	lb.	$4.00
Alfalfa hay mix - Orchardgrass	lb.	$2.50
Winter Wheat seed - Brundage	lb.	$0.26
Soft white winter wheat average price 2013		$0.28
Hard Red Spring Wheat - Kelse	lb.	$0.57
Hard Red Spring Wheat, average 2013 price	lb.	$0.30
Spring Barley - Bob	lb.	$0.53
Winter Triticale - Trimark336	lb.	$0.20
Winter Pea - Windham	lb.	$0.60
Spring Pea - Aragorn	lb.	$0.27
Fertilizer:		
Nitrogen (dry)	lb.	$0.70
Phosphorous (dry)	lb.	$0.66
Sulfur (dry)	lb.	$0.56
Potassium (dry)	lb.	$0.36
Raw poultry manure (wet)	ton	$18.00
Hauling Manure (assume 150 mile radius)	ton	$25.00
Labor:		
Hourly machine labor* *Includes all applicable state and federal taxes.	hour	$20.00
Custom rates (hay crops):		
Custom baling (small bales, 14" x 16", 50 – 60 lb)	bale	$0.70
Custom baling (3'x4', 800 lb)	bale	$11.50
Custom stacking (small bales, 14" x 16")	bale	$0.51
Custom stacking (3 x 4' bales)	bale	$3.00
Land costs:		
Crop-share: Owner percentage	acre	25%
Overhead:		
Overhead Fee (percent of variable costs)	acre	5.00%
Operating Interest:		
Operating Interest (charged on variable costs)	acre	7.00%
Organic Certification Costs:		
Certification fees	acre	$4.00
Administrative labor	hour	$20.00

Table 3.3 Pesticide costs for non-organic crops

Adjuvants:	Unit	Price/unit
Ammonium Sulfate	pt.	$0.35
Crop oil concentrate	oz.	$0.08
M90	oz.	$0.17
R-11 surfactant	oz.	$0.22
Syltac Sticker	pt.	$6.25
InPlace	oz.	$0.28
Herbicides:		
Glyphosate	oz.	$0.19
Huskie	oz.	$0.90
Axial XL	oz.	$1.14
Pre-emergence Credit Extra	pt.	$1.88
Assure II EC	oz.	$0.69
Pursuit	oz.	$3.45
Prowl	oz.	$0.34
Imidan 70	lb.	$12.70
Dimethoate	pt.	$4.88
Osprey	oz.	$3.70
Starane+Salvo	oz.	$0.50
Brox M	oz.	$0.27
Fungicides:		
Quilt	oz.	$1.35
Custom Work:		
Aerial (spray)	acre	$8.95

Table 3.4. Crop prices, farmgate, 2013-2014

Crop	**Unit**	**Price**
Organic soft white winter wheat, food grade	bu	$13.00
Organic hard red spring wheat, feed grade	bu	$16.00
Organic barley, feed grade	ton	$333.00
Organic alfalfa-orchardgrass*	ton	$215.00
Organic winter pea hay**	ton	$200.00
Organic winter triticale, feed grade	bu	$12.00
Conventional soft white wheat	bu	$6.50
Conventional hard red spring wheat (DNSW)	bu	$8.00
Conventional spring pea	lb	$0.14

Sources: Organic grain prices are estimates provided by Grain Miller's Inc., valid for the Northwest region of the U.S (Spring 2014) and verified by comparison to average prices provided by USDA-AMS Livestock and Grain Market News (http://www.ams.usda.gov).
*Average price for pure conventional alfalfa was used. Pure organic alfalfa prices ranged from $250-300 per ton, but prices for organic alfalfa-grass blends were unavailable. The price presented here is a conservative estimate.
**No prices for organic winter pea hay were available. It is a high quality forage with similar end use markets to alfalfa, thus we valued it higher than grass-hay prices, but lower than alfalfa.

Table 3.5. Costs for transporting organic crops to market ($/ac)

Cost per acre	Unit	Winter Wheat	Spring Wheat	Spring Barley	Winter Triticale
Bushel weight by crop	lb/bu	60	60	48	52
Divide 40 ton truck limit by lb/bu	bu/load	1333	1333	1667	1538
Enter average yield/acre of crop	bu/ac	80	45	60	80
Divide bu/load by yield (bu/acre)	ac/load	16.67	29.63	27.78	19.23
Cost per mile	$/mile	$3.90	$3.90	$3.90	$3.90
Miles to market	mile	200	200	200	200
Total cost of full load	$	$780	$780	$780	$780
Cost of truck divided by ac/load =	**$/acre**	**$47**	**$26**	**$28**	**$41**

Sources: Grain Transportation Quarterly Updates, USDA-AMS report, 2012, rate for 200 miles in the Western region of the U.S (40 ton truck limit). (See http://www.ams.usda.gov/AgTransportation)

Table 3.6. Machinery complement for a 2,000-acre conventional farm that includes 100 acres of organic, reduced-till production

Type of Machine	Replacement Value ($)	Age When Purchased	Years of Life	Annual Hours of Use	Salvage Value ($)	Annual Repairs ($) (Materials & Labor)	Gallons of Fuel/Hr	Taxes, Housing, Insurance, Licenses (%)	Labor Multiplier	Acres per Hour
Tractors, ATVs:										
4WD-ATV	5,000	0	10	150	1,500	75	1.2	1.2	1.0	NA
300HP Challenger Tractor	180,000	5	15	600	25,000	5,000	10	1.1	1.1	NA
Equipment:										
30' Disk Drill	35,000	0	12	170	5,000	2,800	13	0.6	1.2	13
50' Rotary Hoe	19,800	10	20	100	3,600	500	10	0.6	1.1	56
53' Rotary Harrow	19,500	10	25	100	3,900	500	9	0.6	1.1	22
33' Undercutter	20,000	10	15	25	4,000	400	10	0.6	1.1	16
20' Flail Shredder	14,000	0	10	150	2,500	1,100	9	2.5	1.1	12
425 bu Manure Spreader	39,000	0	12	150	8,000	3,000	10	0.6	1.2	51
Combine, 25' Header	178,000	0	15	200	35,000	5,760	7	2.6	1.2	6
18' Swather (self-propelled)	66,500	0	10	250	12,500	2,500	4.8	3.2	1.2	9
Side Delivery Rake (tractor pulled)	12,000	0	10	200	3,000	500	9	0.6	1.1	12
Brillion seeder (12')	9,500	0	12	100	1,500	500	9	3	1.2	5
2-tie baler	42,000	2	10	150	8,500	2,000	10	2.5	1.2	11
70' Rental Sprayer	--	--	--	--	--	--	--	--	--	35
Trucks:				Miles/ year			Miles per gal			
2-Ton Truck	20,000	15	15	2,000	4,000	1,250	6	10.1	1.2	
Tandem Axle Truck	35,000	15	20	4,000	4,500	2,000	6	10.1	1.2	
3/4-Ton Pickup	22,000	0	10	12,000	7,500	1,500	12	6.8	1.2	

Note: A 2,000-acre farm was used to calculate machine costs. Equipment is assumed to be used on all 2,000 acres.

Table 3.7. Management fees for conventional crops

Average Management Fees for Conventional crops	Price/ Acre
Alfalfa	$14.00
Spring Barley	$14.00
Winter Triticale	$14.00
Winter pea green manure	$14.00
Winter pea hay	$14.00
Spring Wheat	$22.00
Winter wheat	$26.00

Note: Calculated as 5% of gross revenue from 2013 direct seed crop budgets, available at http://web.cals.uidaho.edu/idahoagbiz/enterprise-budgets/

Table 3.8 Multi-peril yield protection crop insurance for 35 acres, insured at 75% of crop value in the state of Idaho*

Crop	Estimated Approved Yield (unit/acre)	Crop Insurance Premium ($/acre)	Liability coverage ($/acre)
Organic Soft white winter wheat	62 bu	$4.50	$312
Organic Hard red spring wheat	32 bu	$7.50	$180
Organic Barley	40 bu	$6.50	$122
Organic Winter Triticale**	62 bu	$4.50	$312
Organic Alfalfa-orchardgrass***	1.6 ton	$9.00	$276
Conventional soft white wheat	62 bu	$4.50	$312
Conventional hard red spring wheat	45 bu	$7.00	$255
Conventional Spring Pea	1,500 lb	$9.50	$214

*Idaho was used as the location for insurance calculations because the option for non-irrigated organic crops in the USDA Risk Management Agency cost calculator was provided. The only categories for organic crops in the state of Washington were for irrigated crops.

**Since no estimate for winter triticale was available, the premium for winter wheat was used as an estimate.

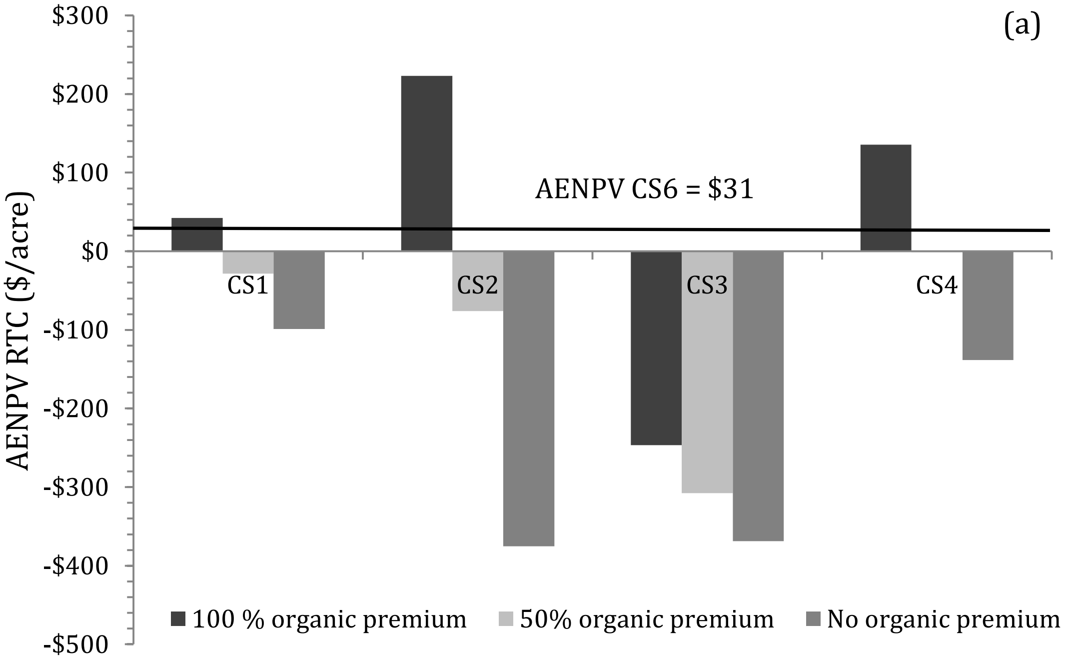
***Based on estimate from Oregon for organic irrigated pure alfalfa.

Table 3.9 Summary of yield, costs and revenue

		Unit	Yield per acre	Price /unit	Revenue /acre	TC[1] ($/acre)	Returns over TC ($/acre)	Total VC[2] ($/acre)	Returns over VC ($/acre)	Land Cost[3] ($/acre)
Crop System 1:	**Organic**									
CS1 Year 1	Alfalfa-grass (est)[4]	ton	0.5	$215	$103	$270	-$167	$169	-$65	$26
CS1 Year 2	Alfalfa-grass (Yr 1)	ton	1.7	$215	$357	$411	-$54	$169	$188	$89
CS1 Year 3	Alfalfa-grass (Yr 2)	ton	2.3	$215	$497	$436	$61	$163	$333	$124
CS1 Year 4	Winter wheat	bu	50	$13	$650	$358	$292	$121	$529	$163
CS1 Year 5	Spring Barley	ton	1.9	$333	$623	$466	$157	$233	$391	$156
Crop System 2:	**Organic**									
CS2 Year 1	Winter triticale	bu	94	$12	$1,128	$549	$579	$203	$925	$282
CS2 Year 2	Winter pea hay	ton	0.9	$200	$176	$338	-$162	$229	-$53	$44
Crop System 3:	**Organic**									
CS3 Year 1	Winter pea GM	--	0.0	$0	$0	$313	-$313	$197	-$197	$0
CS3 Year 2	Winter wheat	bu	39	$13	$507	$682	-$175	$121	$386	$127
Crop System 4:	**Organic**									
CS4 Year 1	HR Spring wheat	bu	33	$16	$528	$495	$33	$277	$251	$132
CS4 Year 2	Winter pea hay	ton	1.1	$200	$224	$340	-$116	$220	$4	$56
CS4 Year 3	Winter wheat	bu	84	$13	$1,092	$565	$527	$211	$881	$273
Crop System 5:	**Conventional**									
CS5 Year 1	DN Spring wheat	bu	58	$8	$464	$435	$29	$260	$204	$116
CS5 Year 2	Winter pea hay	ton	0.4	$200	$88	$266	-$178	$197	-$109	$22
CS5 Year 3	Winter wheat	bu	80	$6.50	$520	$438	$82.47	$245	$275	$130
Crop System 6:	**Conventional**									
CS6 Year 1	DN Spring wheat	bu	58	$8	$464	$435	$29	$260	$204	$116
CS6 Year 2	Spring pea	lb	1800	$0.14	$243	$259	($16)	$155	$88	$61
CS6 Year 3	Winter wheat	bu	80	$6.50	$520	$438	$82	$245	$275	$130

[1] TC= Total Cost, [2] VC= Variable Cost, [3] Land cost is calculated as Cost and Crop share, with a 25/75% Landowner/renter agreement, [4] Alfalfa-grass is the alfalfa orchardgrass mix. Est.=establishment year, GM = green manure, HR = hard red, DN = dark northern.

Figure 3.1. Annual Equivalent Net Present Value of Returns over Total Costs(AENPV RTC) (a) and AENPV of Returns over Variable Costs (RVC) (b), assuming Ownership scenario of four ORT cropping systems. The Ownership scenario assumes forage harvest is included in the on-farm machinery compliment.



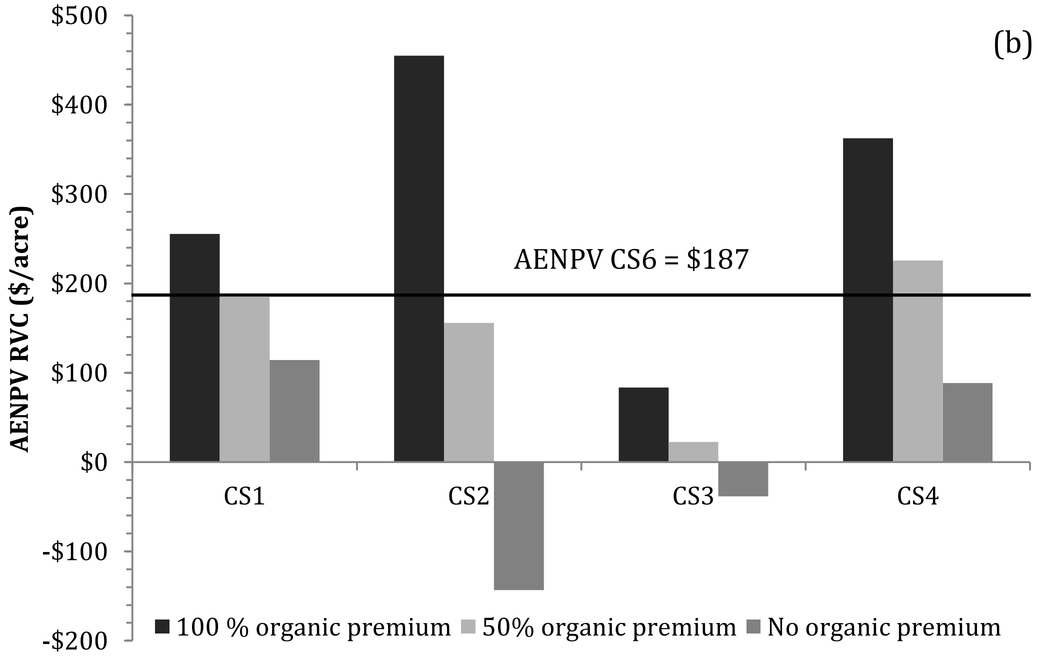


Figure 12. Annual Equivalent Net Present Value of Returns over Total Costs (AENPV RTC) (a) and AENPV of Returns over Variable Costs (RVC) (b) for the Custom scenario of four ORT cropping systems. The Custom scenario assumes forage harvest is custom hired. Custom scenario machine costs include total machine costs plus the cost of the custom job.

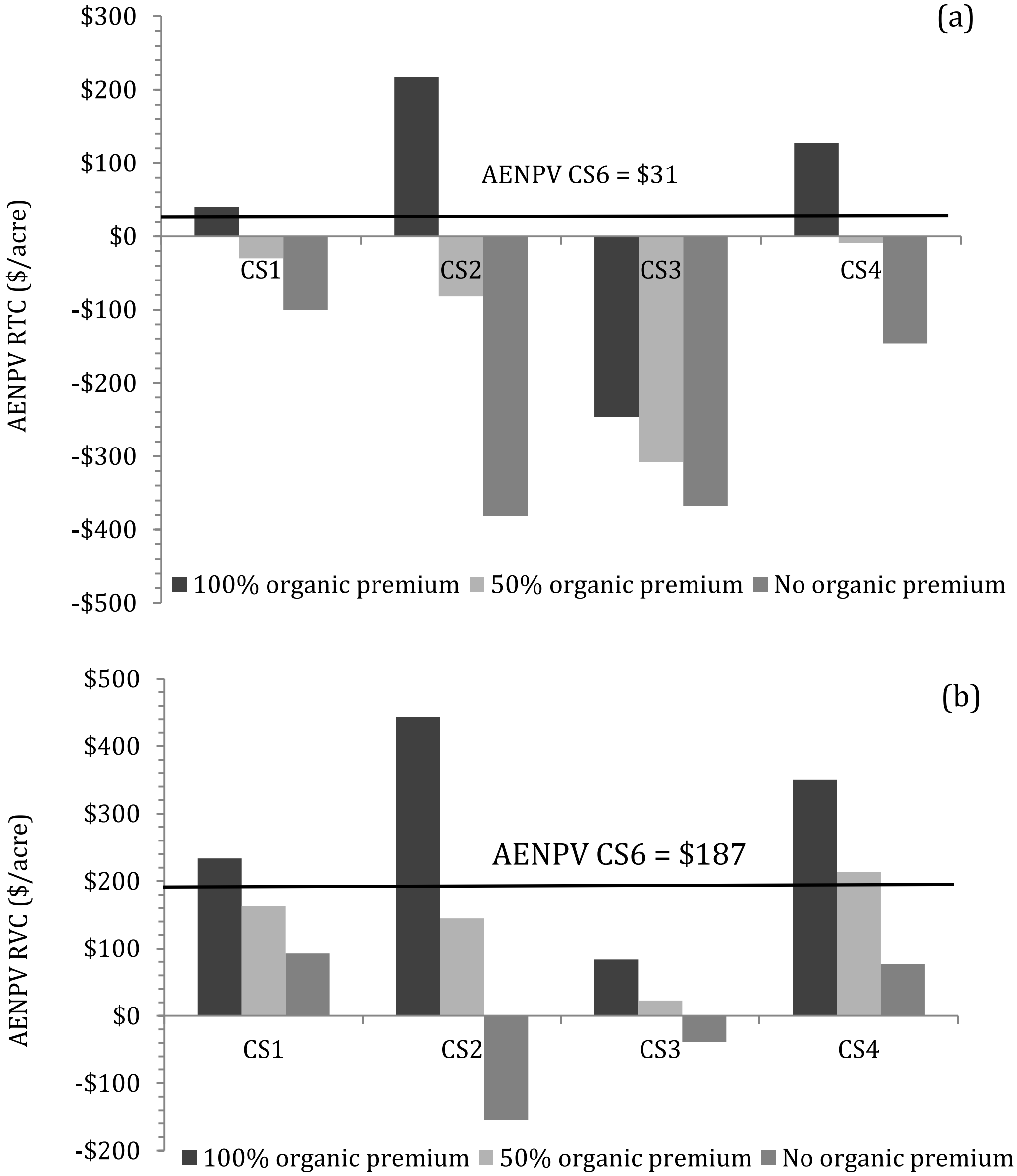


Figure 3.3. Average annual machine costs for three ORT cropping systems (CS1, CS2, CS4) and one non-organic reduced-till cropping system (CS5) (see Table 1 for descriptions). The Ownership scenario assumes forage harvest is included in the on-farm machinery complement, and the Custom scenario assumes forage harvest is custom hired. Custom scenario machine costs include total machine costs plus the cost of the custom job.

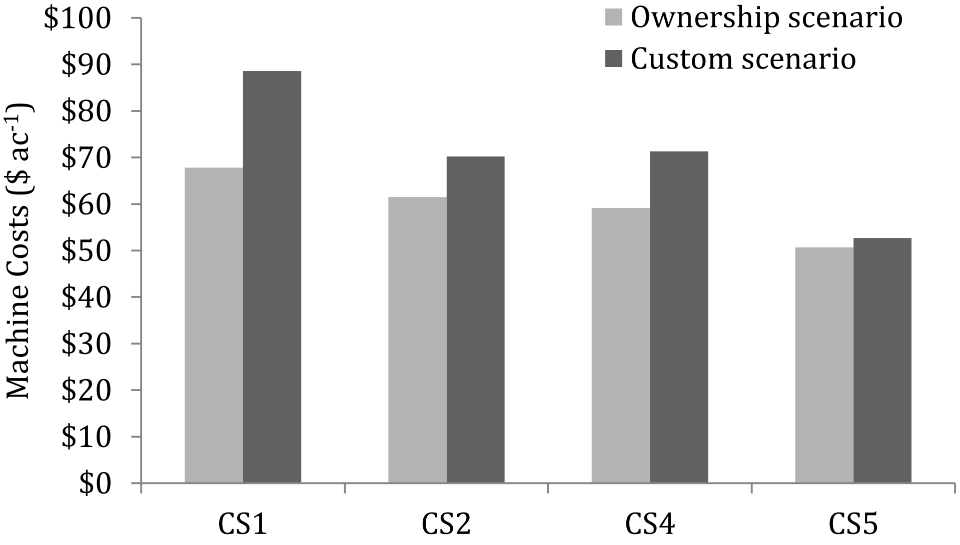


Figure 3.4. Total variable costs (far left column) and components of variable costs for two organic cropping systems (CS1 and CS2) and one non-organic system (CS6)

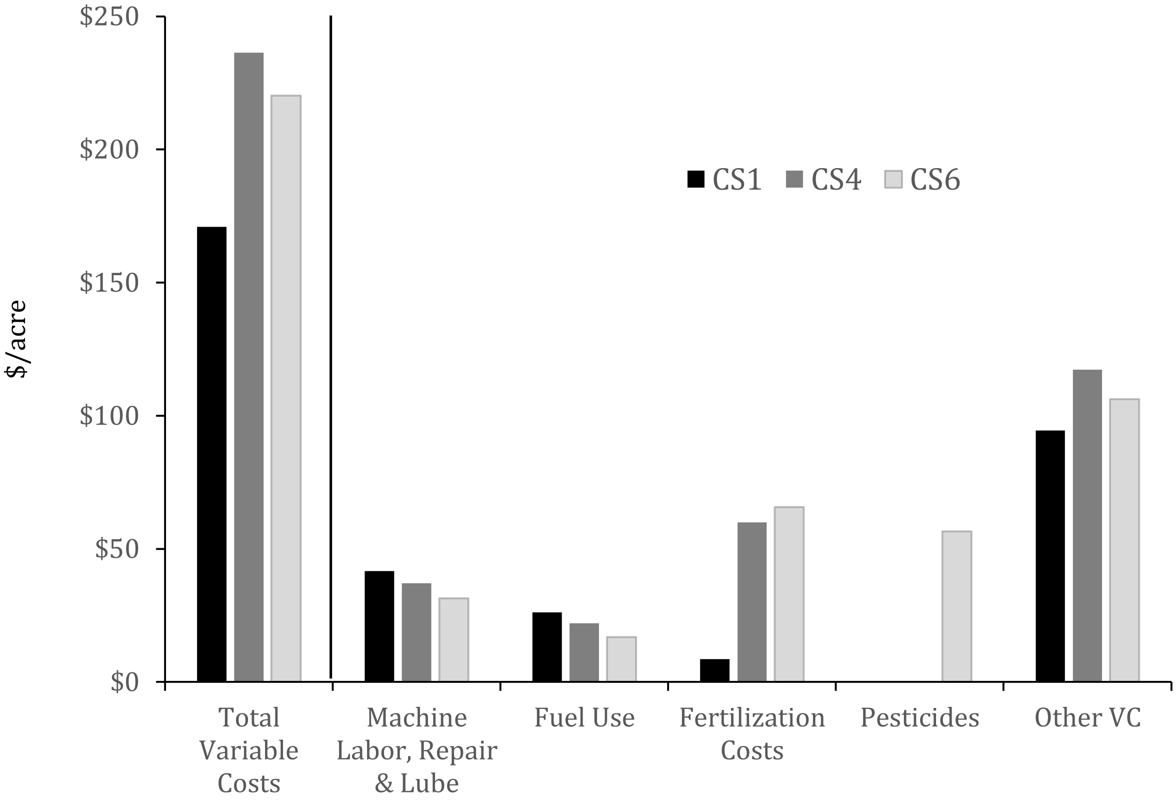
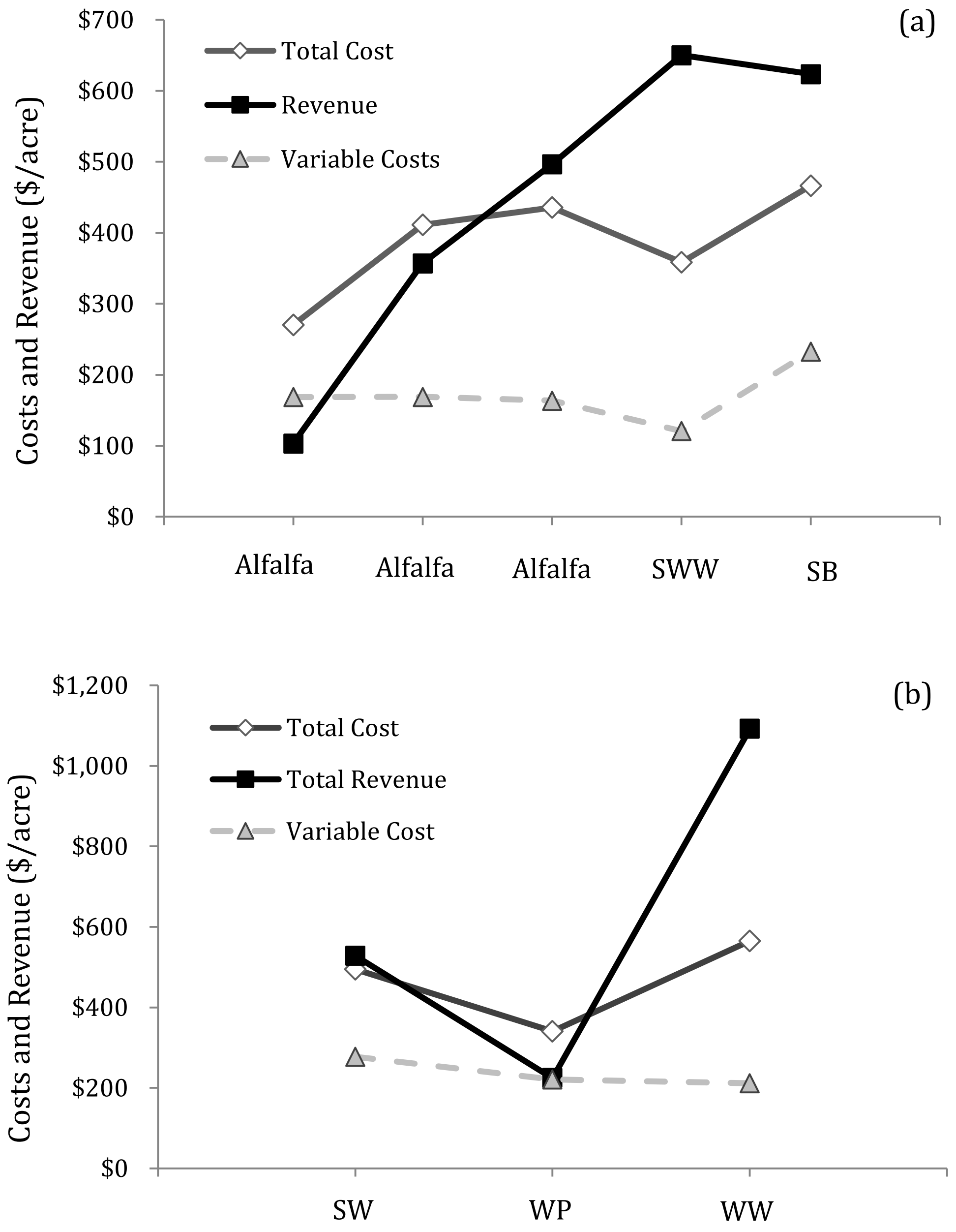
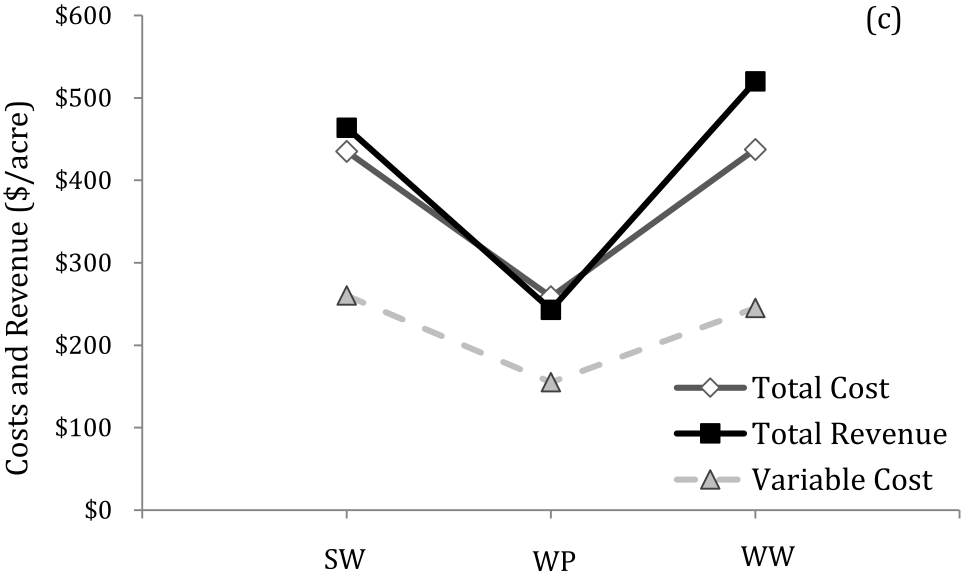


Figure 3.5. Revenue over total and variable costs of two ORT cropping systems, CS1 (a), CS4 (b), and one non-organic cropping system, CS6 (c).




(c)
Costs and Revenue ($/acre)
$600
$500
$400
$300
$200
$100
$0
SW
WP
WW
Total Cost
Total Revenue
Variable Cost

3.7 References

Archer, D.W., A.A. Jaradat, J.M.-F. Johnson, S.L. Weyers, R.W. Gesch, F. Forcella, and H.K. Kludze. 2007. Crop productivity and economics during the transition to alternative cropping systems. Agron. J. 99: 1538–1547.

Berner, A., I. Hildermann, A. Fließbach, L. Pfiffner, U. Niggli, and P. Mader. 2008. Crop yield and soil fertility response to reduced tillage under organic management. Soil Tillage Res. 101(1-2): 89–96.

Birkhofer, K., T.M. Bezemer, J. Bloem, M. Bonkowski, S. Christensen, D. Dubois, F. Ekelund, A. Fließbach, L. Gunst, K. Hedlund, P. Mäder, J. Mikola, C. Robin, H. Setälä, F. Tatin-Froux, W.H. Van der Putten, and S. Scheu. 2008. Long-term organic farming fosters below and aboveground biota: Implications for soil quality, biological control and productivity. Soil Biol. Biochem. 40(9): 2297–2308.

Borrelli, K., R. Koenig, R.S. Gallagher, D. Pittmann, A. Snyder, I. Burke, L. Hoagland, and E.P. Fuerst. 2012. Alternative strategies for transitioning to rrganic production in direct-seeded grain systems in eastern Washington II: Nitrogen fertility. J. Sustain. Agric. 36(4): 461–477.

Boyd, N.S., and E.B. Brennan. 2006. Weed management in a legume-cereal cover crop with the rotary hoe. Weed Technol. 20(3): 733–737.

Brown, T.T., R.T. Koenig, D.R. Huggins, J.B. Harsh, and R.E. Rossi. 2008. Lime effects on soil acidity, crop yield, and aluminum chemistry in direct-seeded cropping systems. Soil Sci. Soc. Am. J. 72(3): 634.

Capital Press. 2014. Available at http://www.cpmarketplace.com.

Dimitri, C., and L. Oberholtzer. 2009. Marketing U.S. organic goods: Recent trends from farms to consumers.

Fließbach, A., H.-R. Oberholzer, L. Gunst, and P. Mäder. 2007. Soil organic matter and biological soil quality indicators after 21 years of organic and conventional farming. Agric. Ecosyst. Environ. 118: 273–284.

Fredriksson, H., L. Salomonsson, R. Andersson, and A.-C. Salomonsson. 1998. Effects of protein and starch characteristics on the baking properties of wheat cultivated by different strategies with organic fertilizers and urea. Atta Agric Scand., Sect. B, Soil Plant Sci. 48: 49–57.

Fuerst, E.P., R.T. Koenig, J. Kugler, K. Painter, M. Stannard, and J. Goldberger. 2009. Organic alfalfa management guide. Washington State University Extention. EB2039E.

Fuerst, E.P., E.Y. Park, C.F. Morris, S. Machado, P.R. Miller, I.C. Burke, E. Wegner, and B.-K. Baik. 2011. CAHNRS and WSU Extension Wheat and Small Grains: End-Use Quality and Nutritional Aspects of Organic, No-till, and Conventional Dryland Wheat. End-Use Qual. Nutr. Asp. Org. No-till, Conv. Dryl. WheatAvailable at http://smallgrains.wsu.edu/does-organic-production-result-in-lower-protein-content/ (verified 1 May 2014).

Gadermaier, F., A. Berner, A. Fließbach, J.K. Friedel, and P. Mäder. 2012. Impact of reduced tillage on soil organic carbon and nutrient budgets under organic farming. Renew. Agric. Food Syst. 27(01): 68–80.

Gallagher, R.S., D. Pittmann, A.M. Snyder, R.T. Koenig, E.P. Fuerst, I.C. Burke, and L. Hoagland. 2010. Alternative strategies for transitioning to organic production in direct-seeded grain systems in eastern Washington I: Crop agronomy. J. Sustain. Agric. 34(5): 483–503.

Goldberger, J.R., S. Connor, and J. Miller. 2010. The experiences and perspectives of Idaho's certified organic producers: Results from a statewide survey. Sustain. Pacific Northwest 8(2): 8 – 11.

Grant, C.A., G.A. Peterson, and C.A. Campbell. 2002. Nutrient considerations for diversified cropping systems in the Northern Great Plains. Agron. J. 94(March-April 2002): 186–198.

Greene, C., C. Dimitri, B.-H. Lin, W. McBride, L. Oberholtzer, and T. Smith. 2009. Emerging issues in the U.S. organic industry. Econ. Inf. Bull. Number 55.

Greene, C., E. Slattery, and W. Mcbride. 2010. America' s Organic Farmers Face Issues and Opportunities Highlights (USDA-ERS). : 1–8Available at http://www.ers.usda.gov/amber-waves/2010-june/america%E2%80%99s-organic-farmers-face-issues-and-opportunities.aspx#.U6N1Ai8k_lI (verified 19 June 2014).

ISDA (Idaho State Department of Agriculture). 2006. Application Organic Certification. Available at http://www.agri.idaho.gov/Categories/ PlantsInsects/Organic/indexOrganicHome.php (verified 27 April 2014).

Jones, S.S., K.K. Kidwell, J. Dawson, R.A. Jussaume, J. Goldberger, R. Krebill-Prather, and L. Glenna. 2006. Wheat production in Washington, Washington State University Summary Report CSS Information Series No. 1202-06. (November)Available at http://www.crs.wsu.edu/wheatproduction/ index.html (verified 20 December 2012).

Kirby, E., and D. Granatstein. 2014. Certified Organic Acreage and Sales in Washington State: 2013, Organic Trends series. Wenachee, WA.

Kok, H., R.I. Papendick, and K.E. Saxton. 2009. STEEP: Impact of long-term conservation farming research and education in Pacific Northwest wheatlands. J. Soil Water Conserv. 64(4): 253–264.

Liebman, M., and A.S. Davis. 2000. Integration of soil, crop and weed management in low-external-input farming systems. Weed Res. 40: 27–47.

Mahler, R.. 2002. Impacts and management of soil acidity under direct seed systems: Status and effects on crop production. *In* Pacific Northwest Conservation Tillage Systems Information Source Direct Seed Conference. Spokane, WA.

McBride, W.D., C. Greene, M. Ali, and L. Foreman. 2012. The structure and profitability of organic field crop production: The case of wheat. Selected Paper for the Agricultural and Applied Economics Association's 2012 Annual Meeting, August 12-14, 2012. Seattle, Washington.

McCool, D.K., D.R. Huggins, K.E. Saxton, and A.C. Kennedy. 2001. Factors affecting agricultural sustainability in the Pacific Northwest , USA: An overview. p. 255–260. *In* Sustaining the Global Farm. Selected papers from the 10th International Soil Conservation Organization Meeting held May 24-29, 1999 at Purdue University and the USDA-ARS National Soil Erosion Research Laboratory.

Miller, P.R., D.E. Buschena, C. a. Jones, and J. a. Holmes. 2008. Transition from intensive tillage to no-tillage and organic diversified annual cropping systems. Agron. J. 100(3): 591–599.

Murphy, K.M., K.G. Campbell, S.R. Lyon, and S.S. Jones. 2007. Evidence of varietal adaptation to organic farming systems. F. Crop. Res. 102(3): 172–177.

Osteen, C., J. Gottlieb, and U. Vasavada. 2012. Agricultural Resources and Environmental Indicators, 2012 Edition, EIB 98. U.S. Department of Agriculture, Economic Research Service, August 2012.

Painter, K.M., and H. Donlon. 2013. Idaho AgBiz: Costs of production. 2013 Direct Seed Budgets North. IdahoAvailable at http://web.cals.uidaho.edu/idahoagbiz/enterprise-budgets/ (verified 1 May 2014).

Painter, K., D. Granatstein, E. Kirby, and L. Carpenter-Boggs. 2007. Research brief: Market and opportunities for organic feed production in eastern Washington. Sustain. Pacific Northwest Newsl. Vol. 5 No. 1 5(1).

Park, E.Y., E.P. Fuerst, P.R. Miller, S. Machado, I.C. Burke, and B.-K. Baik. 2011. CAHNRS and WSU Extension Wheat and Small Grains: Does organic production result in lower protein content? Funct. Nutr. Charact. Wheat Grown Org. , No-till , Conv. Crop. Syst. Available at http://smallgrains.wsu.edu/does-organic-production-result-in-lower-protein-content/ (verified 1 May 2014).

Patterson, P.E., and K.M. Painter. 2013. 2013 Crop Input Cost Summary. Agric. Econ. Ext. Ser. No. 13-03: 0–27.

Peigné, J., B.C. Ball, J. Roger-Estrade, and C. David. 2007. Is conservation tillage suitable for organic farming? A review. Soil Use Manag. 23(2): 129–144.

Peoples, M.B., D.F. Herridge, B.R. Alves, S. Urquiaga, R.M. Boddey, F.D. Dakora, S. Bhattarai, S.L. Maskey, C. Sampet, B. Rerkasem, D.F. Khans, B.S. Jensen, P. Industry, G.P.O. Box, S. Asia, S. Asia, S. Asia, S. Asia, S. Asia, and S. Asia. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48: 1–17.

Pimentel, D., P. Hepperly, J. Hanson, D. Douds, and R. Seidel. 2005. Environmental, energetic, and economic comparisons of organic and conventional farming systems. Bioscience 55(7): 573–582.

De Ponti, T., B. Rijk, and M.K. van Ittersum. 2012. The crop yield gap between organic and conventional agriculture. Agric. Syst. 108: 1–9.

Reganold, J.P. 1988. Comparison of soil properties as influenced by organic and conventional farming systems. Am. J. Altern. Agric. 3(4): 144–145.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2003. Dryland Cropping in the Western United States. *In* Pacific Northwest Conservation Tillage Systems Handbook Series No. 28.

Schillinger, W.F., R.I. Papendick, S.O. Guy, P.E. Rasmussen, and C. van Kessel. 2006. Dryland Cropping in the Western United States. p. 365–394. *In* Peterson, G.A., Unger, P.W., Payne, W.A. (eds.), Dryland Agriculture: Agronomy Monograph no. 23, 2nd Ed. American Society of Agronomy, Inc., Crop Science Society of America, Inc., Soil Science Society of America, Inc., Madison, WI.

Smith, E.G., M. Jill Clapperton, and R.E. Blackshaw. 2004. Profitability and risk of organic production systems in the northern Great Plains. Renew. Agric. Food Syst. 19(03): 152–158.

Stockdale, E.A., N.H. Lampkin, M. Hovi, R. Keatinge, E.K.M. Lennartsson, D.W. Macdonald, S. Padel, F.H. Tattersall, M.S. Wolfe, and C.A. Watson. 2001. Agronomic and environmental implications of organic farming systems. Adv. Agron. 70: 261–327.

Teasdale, J.R., C.B. Coffman, and R.W. Mangum. 2007. Potential long-term benefits of no-tillage and organic cropping systems for grain production and soil improvement. Agron. J. 99: 1297–1305.

USDA. 2013. Organic Farming Practices, Risk Management Agency Fact Sheet.

USDA-AMS. 2014a. Agricultural Transportation. Grain Truck and Ocean Rate Advisory: 4th Quarter 2013. Available at www.ams.usda.gov/AgTransportation (verified 1 May 2014).

USDA-AMS. 2014b. Market News: Livestock, Poultry and Grain Market News. Available at http://www.ers.usda.gov/data-products/organic-prices.aspx#.U3v8PS_lf1s (verified 1 May 2014).

USDA-ARS. 2011. Accomplishments Report (2008-2011) National Program 216: Agricultural System Competitiveness and Sustainability.

USDA-ERS. 2012. Prices for organic grains and feedstuffs, regional markets, monthly, 2008-11. Prices Org. grains Feed. Reg. Mark. Mon. 2008-11Available at http://www.ers.usda.gov/data-products/organic-prices.aspx#.U3v8PS_lf1s (verified 1 May 2014).

USDA-ERS. 2013a. Organic Production. Available at http://www.ers.usda.gov/data-products/organic-production.aspx#25766 (verified 5 July 2014).

USDA-ERS. 2013b. Organic Costs and Returns: Wheat Production Costs and Returns from the 2009 ARMS. Available at http://www.ers.usda.gov/data-products/commodity-costs-and-returns/organic-costs-and-returns.aspx#.U1rLacc2P9E (verified 1 May 2014).

USDA-ERS. 2014a. State Fact Sheets: Idaho. Available at http://www.ers.usda.gov/data-products/state-fact-sheets.aspx#.U3_fPi_lf1s (verified 10 April 2014).

USDA-ERS. 2014b. Organic Prices: Wholesale prices for organic grains and feedstuffs, U.S., monthly, 2011-13. Available at http://www.ers.usda.gov/data-products/organic-prices.aspx#.U3v8PS_lf1s (verified 1 May 2014).

USDA-NASS. 2011. Idaho office of USDA's NASS: County Estimates. Crop Cty. Estim.Available at http://www.nass.usda.gov/Statistics_by_State/Idaho/Publications/County_Estimates/index.asp.

USDA-NASS. 2014a. 2012 Census of Agriculture: Washington State and County Data, Volume 1, Geographic Area Series Part 47.

USDA-NASS. 2014b. 2012 Census of Agriculture: Idaho State and County Data, Volume 1, Geographic Area Series Part 12.

USDA-NOP. 2013. USDA Organic Regulations. National Organic Program, U.S.

Watson, C.A., D. Atkinson, P. Gosling, L.R. Jackson, and F.W. Rayns. 2002. Managing soil fertility in organic farming systems. Soil Use Manag. 18(3): 239–247.

Wortman, S.E., T.D. Galusha, S.C. Mason, and C. a. Francis. 2011. Soil fertility and crop yields in long-term organic and conventional cropping systems in Eastern Nebraska. Renew. Agric. Food Syst. 27(03): 200–216.

WSDA (Washington State Department of Agriculture). 2014. Organic Certification Fee Form - Producers. 2259Available at http://agr.wa.gov/foodanimal/organic/foodproducers.aspx (verified 27 April 2014).

Young, D.L., T.-J. Kwon, and F.L. Young. 1994. Profit and risk for integrated conservation farming systems in the Palouse. J. Soil Water Conserv. 49(6): 601–606.

Appendix A. Machine costs

Machinery Costs for cropping systems CS1-CS6, listed by individual crops in rotation

Machinery Costs CS1-Yr1, Organic Alfalfa-grass hay (establishment year) ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	Total Cost ($/acre)
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/acre	hr/ acre	gal/ acre	
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
Total:	$26.90	$15.79	$4.51	$47.20	$14.72	$34.69	$5.19	$55.52	$29.50	1.48	10.20	$131.29

Machinery Costs CS1-YR2, Organic Alfalfa-grass hay (year 1 production) ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	Total Cost ($/acre)
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$19.49	$10.24	$4.15	$33.88	$11.65	$27.45	$4.11	$44.13	$26.51	1.33	8.07	$103.59

Machinery Costs CS1-YR3, Organic Alfalfa-grass hay (Year 2 production) ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/acre)
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	$0.05	$0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	$0.05	$0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$18.16	$9.52	$3.94	$31.62	$10.93	$24.91	$3.73	$40.49	$24.91	1.25	7.32	$96.09

Machinery Costs for CS1-YR4, Organic Soft White Winter Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/acre)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$17.79	$11.27	$5.31	$34.37	$11.42	$18.66	$2.79	$33.79	$20.17	1.01	5.48	$87.40

Machinery Costs for CS1-YR5, Organic Spring Barley ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depreciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubricants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/acre)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
AGCO 425 bu manure spreader	$0.50	$0.29	$0.04	$0.83	$0.47	$0.67	$0.10	$1.24	$0.33	0.02	0.20	$2.40
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$25.34	$16.26	$5.93	$47.53	$14.83	$24.99	$3.74	$44.48	$24.27	1.21	7.35	$115.35

Table 7.2

Machinery Costs for CS2-YR1, Organic Winter Triticale (grain) ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
AGCO 425 bu manure spreader	$0.50	$0.29	$0.04	$0.83	$0.47	$0.67	$0.10	$1.24	$0.33	$0.02	$0.20	$2.40
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$18.29	$11.56	$5.35	$35.20	$11.89	$19.33	$2.89	$35.03	$20.50	1.03	5.68	$89.80

Machinery Costs for CS2-YR2, Organic Winter Pea Hay ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	Hr/ acre	gal/ acre	Total Cost ($/ac)
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
Brillion seeder	$2.95	$1.70	$0.55	$5.20	$1.80	$6.01	$0.90	$8.71	$3.46	0.17	1.77	$17.37
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$19.05	$10.97	$3.78	$33.80	$10.98	$27.98	$4.18	$44.06	$25.17	1.26	8.23	$102.10

Table 7.3

Machinery Costs for CS3-YR1, Organic Winter Pea Green Manure ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
300HP Tractor with:												
Brillion seeder	$2.95	$1.70	$0.55	$5.20	$1.80	$6.01	$0.90	$8.71	$3.46	0.17	1.77	$17.37
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$13.41	$8.30	$2.77	$24.48	$7.71	$22.10	$3.31	$34.04	$19.89	0.99	6.50	$77.48

Machinery Costs for CS3-YR2, Organic Soft White Winter Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$17.79	$11.27	$5.31	$34.37	$11.42	$18.66	$2.79	$33.79	$20.17	1.01	5.48	$87.40

Machinery Costs for CS4-YR1, Organic Hard Red Spring Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr /acre	gal/acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
AGCO 425 bu manure spreader	$0.50	$0.29	$0.04	$0.83	$0.47	$0.67	$0.10	$1.24	$0.33	0.02	0.20	$2.40
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$22.15	$14.19	$5.68	$42.02	$13.57	$22.86	$3.42	$40.77	$22.89	1.14	6.72	$104.75

Machinery Costs for CS4-YR2, Organic Winter Pea Hay ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depreciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubricants	Total	($/acre)	(hr/acre)	(gal/acre)	Total Cost ($/ac)
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
Brillion seeder	$2.95	$1.70	$0.55	$5.20	$1.80	$6.01	$0.90	$8.71	$3.46	0.17	1.77	$17.37
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
20' Flail Shredder (Bush hog)	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$17.05	$9.69	$3.49	$30.23	$9.84	$24.04	$3.59	$38.39	$22.56	1.13	7.07	$90.25

Machinery Costs for CS4-YR3, Organic Soft White Winter Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/acre	hr/acre	gal/acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
AGCO 425 bu manure spreader	$0.50	$0.29	$0.04	$0.83	$0.47	$0.67	$0.10	$1.24	$0.33	0.02	0.20	$2.40
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
33' Undercutter	$3.19	$2.07	$0.25	$5.51	$1.26	$2.13	$0.32	$3.71	$1.38	0.07	0.63	$10.60
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$18.29	$11.56	$5.35	$35.20	$11.89	$19.33	$2.89	$35.03	$20.50	1.03	5.68	$89.80

Machinery Costs for CS5-YR1, Conventional Dark Northern Spring Wheat (DNSW) ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depreciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubricants	Total	$/acre	hr/acre	gal/acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$14.48	$9.05	$5.06	$28.59	$10.04	$17.31	$2.59	$30.86	$19.30	$0.97	$5.09	$77.82

Machinery Costs for CS5-YR2, Conventional Winter Pea Hay ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
18' Swather	$2.48	$1.04	$0.58	$4.10	$1.15	$1.87	$0.28	$3.30	$2.75	0.14	0.55	$10.15
300HP Tractor with:												
Brillion seeder	$2.95	$1.70	$0.55	$5.20	$1.80	$6.01	$0.90	$8.71	$3.46	0.17	1.77	$17.37
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
50' Rotary Hoe	$0.28	$0.21	$0.03	$0.52	$0.16	$0.61	$0.09	$0.86	$0.31	0.02	0.18	$1.69
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
Side delivery rake	$1.11	$0.66	$0.12	$1.89	$0.57	$2.63	$0.39	$3.59	$1.89	0.09	0.77	$7.37
2-tie baler	$2.99	$1.34	$0.47	$4.80	$2.01	$3.12	$0.47	$5.60	$1.54	0.08	0.92	$11.94
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$13.43	$7.22	$3.19	$23.84	$8.28	$21.37	$3.20	$33.77	$20.65	1.03	6.28	$77.33

Machinery Costs for CS5-YR3, Soft White Winter Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depreciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubricants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$14.48	$9.05	$5.06	$28.59	$10.04	$17.31	$2.59	$30.86	$19.30	0.97	5.09	$77.82

Machinery Costs for CS6-YR1, Conventional Hard Red Spring Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depreciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubricants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
Total:	$14.48	$9.05	$5.06	$28.59	$10.04	$17.31	$2.59	$30.86	$19.30	$0.97	$5.09	$77.82

Machinery Costs for CS6-YR2, Conventional Spring Pea ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Owner-ship Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/pea	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.77	0.19	1.10	$27.08
300HP Tractor with:												
Brillion seeder	$2.95	$1.70	$0.55	$5.20	$1.80	$6.01	$0.90	$8.71	$3.46	0.17	1.77	$17.37
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
Total:	$13.67	$8.53	$4.96	$27.16	$9.12	$16.00	$2.39	$28.43	$19.07	0.95	4.70	$73.73

Machinery Costs for CS6-YR3, Conventional Soft White Winter Wheat ($/acre)

	Ownership Costs ($/acre):				Operating Costs ($/acre):				Labor		Fuel Use	
	Depre-ciation	Interest	Taxes, Housing, Insurance, Licenses	Total Ownership Costs	Repairs	Fuel	Lubri-cants	Total	$/ acre	hr/ acre	gal/ acre	Total Cost ($/ac)
Tandem Axle	$1.02	$0.57	$1.00	$2.59	$1.00	$1.13	$0.17	$2.30	$2.40	0.12	0.33	$7.29
3/4 Ton Pickup	$0.73	$0.42	$0.50	$1.65	$0.75	$1.75	$0.26	$2.76	$4.80	0.24	0.51	$9.21
2 Ton Truck	$0.53	$0.35	$0.61	$1.49	$0.63	$0.57	$0.09	$1.29	$1.20	0.06	0.17	$3.98
4WD-ATV	$0.23	$0.20	$0.03	$0.46	$0.05	$0.18	$0.03	$1.18	$2.00	0.10	0.05	$2.71
25' Combine/grain	$7.49	$4.81	$2.18	$14.48	$4.53	$3.74	$0.56	$8.83	$3.02	0.15	1.10	$26.33
300HP Tractor with:												
30' Disk Drill	$1.76	$0.94	$0.36	$3.06	$1.58	$3.38	$0.51	$5.47	$1.83	0.09	1.00	$10.36
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
70' Rental Sprayer	$0.24	$0.16	$0.03	$0.43	$0.12	$0.87	$0.13	$1.12	$0.48	0.02	0.26	$2.03
20' Flail Shredder	$1.33	$0.72	$0.21	$2.26	$0.72	$2.54	$0.38	$3.64	$1.60	0.08	0.75	$7.50
53' Rotary Harrow	$0.67	$0.56	$0.08	$1.31	$0.42	$1.40	$0.21	$2.03	$1.01	0.05	0.41	$4.35
Total:	$14.48	$9.05	$5.06	$28.59	$10.04	$17.31	$2.59	$30.86	$19.30	$0.97	$5.09	$77.82

Appendix B. Crop budgets

Annual crop budgets listed sequentially by crops in rotation for CS1-CS6 under the Full Ownership Scenario

Production Costs for CS1-YR1, Organic Alfalfa-orchardgrass, Establishment year				
Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns:				
Alfalfa-orchardgrass hay	0.5	tons	$215.00	$107.50
Variable Inputs:				
Seed:				$60.50
Ladak	12	lb	$4.00	$48.00
Orchardgrass	5	lb	$2.50	$12.50
Machinery:				$84.09
Fuel	10.20	gal	$3.40	$34.68
Lubricants	1	acre	$5.19	$5.19
Machinery Repairs	1	acre	$14.72	$14.72
Machinery Labor	1.48	acre	$20.00	$29.50
Other:				$24.00
Crop Insurance	1	acre	$0.00	$0.00
Organic Certification fees	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$5.90
Total Variable Costs				**$168.59**
Net Returns Above Variable Costs				**-$61.09**
Ownership (Fixed) Costs:				
Machinery depreciation			$26.90	$26.90
Machinery interest			$15.79	$15.79
Machinery insurance, taxes housing, license			$4.51	$4.51
Land Cost*	1	acre	$26.88	$26.88
*Based on landlord crop-share	25%			
Overhead[2]				$8.43
Management Fee[3]				$19.00
Total Ownership Costs				**$101.50**
Total Costs per Acre				**$270.09**
Returns to Risk				**-$162.59**

Notes: [1] Calculated as 7% interest on operating capital for 6 months.

[2] Covers legal, accounting, and utility fees. Calculated as 5% of operating expenses.

[3] Management fee is calculated as 35% greater than average management for conventional crops.

Production Costs for CS1-YR2, Organic Alfalfa-orchardgrass, Year 1 production				
Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns:				
Alfalfa Hay	1.7	tons	$215.00	$365.50
Variable Inputs:				
Seed:				$60.50
Ladak	12	lb	$4.00	$48.00
Orchardgrass	5	lb	$2.50	$12.50
Machinery:				$69.71
Fuel	8.07	gal	$3.40	$27.44
Lubricants	1	acre	$4.11	$4.11
Machinery Repairs	1	acre	$11.65	$11.65
Machinery Labor	1.33	acre	$20.00	$26.51
Other:				$33.00
Crop Insurance	1	acre	$9.00	$9.00
Organic Certification fees	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$5.71
Total Variable Costs				**$168.92**
Variable Costs per Unit				$99.37
Net Returns Above Variable Costs				**$196.58**
Ownership (Fixed) Costs:				
Machinery depreciation			$19.49	$19.49
Machinery interest			$10.24	$10.24
Machinery insurance, taxes housing, license			$4.15	$4.15
Amortized Establishment Cost				$89.93
Land Cost*	1	acre	$91.38	$91.38
*Based on landlord crop-share	25%			
Overhead[2]				$8.16
Management Fee[3]				$19.00
Total Ownership Costs				**$242.35**
Ownership Costs per Unit				$142.56
Total Costs per Acre				**$411.27**
Total Cost per Unit				$241.92
Returns to Risk				**-$45.77**

Production Costs for CS1-YR3, Organic Alfalfa-orchardgrass, Year 2 production

Item	Quantity Per Acre	Unit	Price or Cost/Unit	Value or Cost/Acre
Gross Returns				
Alfalfa Hay	2.3	tons	$215.00	$494.50
Variable Inputs				
Seed:				$60.50
Ladak	12	lb	$4.00	$48.00
Orchardgrass	5	lb	$2.50	$12.50
Machinery:				$64.47
Fuel	7.32	gal	$3.40	$24.90
Lubricants	1	acre	$3.73	$3.73
Machinery Repairs	1	acre	$10.93	$10.93
Machinery Labor	1.25	hour	$20.00	$24.91
Other:				$33.00
Crop Insurance	1	acre	$9.00	$9.00
Organic Certification fees	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$5.53
Total Variable Costs				**$163.50**
Variable Costs per Unit				$71.09
Net Returns Above Variable Costs				**$331.00**
Ownership (Fixed) Costs:				
Machinery depreciation			$18.16	$18.16
Machinery interest			$9.52	$9.52
Machinery insurance, taxes housing, license			$3.94	$3.94
Amortized Establishment Cost				$89.93
Land Cost*	1	acre	$123.63	$123.63
*Based on landlord crop-share	25%			
Overhead[2]				$7.90
Management Fee[3]				$19.00
Total Ownership Costs				**$272.07**
Ownership Costs per Unit				$272.07
Total Costs per Acre				**$435.57**
Total Cost per Unit				$435.57
Returns to Risk				**$58.93**

Production Costs for CS1-YR4, Organic Soft White Winter Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$620.30
Soft white winter wheat	50	bu	$13.00	$650.00
Dockage	4.57%			-$29.71
Variable Inputs				
Seed:				$35.10
Winter wheat seed - Brundage	135	lb	$0.26	$35.10
Machinery:				$53.03
Fuel	5.48	gal	$3.40	$18.65
Lubricants	1	acre	$2.79	$2.79
Machinery Repairs	1	acre	$11.42	$11.42
Machinery Labor	1.01	hour	$20.00	$20.17
Other:				$28.50
Crop Insurance	1	acre	$4.50	$4.50
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$4.08
Total Variable Costs				$120.71
Variable Costs per Unit				$2.41
Net Returns Above Operating Expenses				**$529.29**
Ownership (Fixed) Costs:				
Machinery depreciation			$17.79	$17.79
Machinery interest			$11.27	$11.27
Machinery insurance, taxes housing, license			$5.31	$5.31
Land Cost*	1	acre	$162.50	$162.50
*Based on landlord crop-share	25%			
Overhead[2]				$5.83
Management Fee[3]				$35.00
Total Ownership Costs				$237.70
Ownership Costs per Unit				$4.75
Total Costs per Acre				$358.41
Total Cost per Unit				$7.17
Returns to Risk				**$291.59**

Production Costs for CS1-YR5, Organic Spring Barley (grain)				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$571.26
Spring Barley	1.9	bu	$333.00	$623.38
Dockage	8.36%			-$52.11
Variable Inputs				
Seed:				$71.55
Spring Barley seed - Bob	135	lb	$0.53	$71.55
Fertilizer:				$43.00
Manure or organic fertilizer	1.0	ton	$18.00	$18.00
Hauling Manure (150 miles)	1.0	ton	$25.00	$25.00
Machinery:				$67.82
Fuel	7.35	gal	$3.40	$24.98
Lubricants	1	acre	$3.74	$3.74
Machinery Repairs	1	acre	$14.83	$14.83
Machinery Labor	1.21	hour	$20.00	$24.27
Other:				$42.50
Crop Insurance	1	acre	$6.50	$6.50
Organic Certification	1	acre	$16.00	$16.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$7.87
Total Variable Costs				$232.74
Operating Costs per Unit				$124.33
Net Returns Above Operating Expenses				**$338.52**
Ownership Fixed Costs:				
Machinery depreciation			$25.34	$25.34
Machinery interest			$16.26	$16.26
Machinery insurance, taxes housing, license			$5.93	$5.93
Land Cost*	1	acre	$155.84	$155.84
*Based on landlord crop-share	25%			
Overhead[2]				$11.24
Management Fee[3]				$19.00
Total Ownership Costs				$233.62
Ownership Costs per Unit				$124.80
Total Costs per Acre				$466.36
Total Cost per Unit				$249.12
Returns to Risk				**$104.90**

Production Costs for CS2-YR1, Organic Winter Triticale				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$1,053.55
Winter Triticale	94	bu	$12.00	$1,128.00
Dockage	6.60%			-$74.45
Operating Inputs				
Seed:				$27.00
Winter Triticale - Trimark 336	135	lb	$0.20	$27.00
Fertilizer:				$85.61
Manure or organic fertilizer	1.99	ton	$18.00	$35.84
Hauling Manure (150 miles)		ton	$25.00	$49.78
Machinery:				$54.60
Fuel	5.68	gal	$3.40	$19.32
Lubricants	1	acre	$2.89	$2.89
Machinery Repairs	1	acre	$11.89	$11.89
Machinery Labor	1.03	hour	$20.00	$20.50
Other:				$28.50
Crop Insurance	1	acre	$4.50	$4.50
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$6.85
Total Operating Costs				$202.56
Operating Costs per Unit				$2.15
Net Returns Above Operating Expenses				**$925.44**
Ownership (Fixed) Costs:				
Machinery depreciation			$18.29	$18.29
Machinery interest			$11.56	$11.56
Machinery insurance, taxes housing, licence			$5.35	$5.35
Land Cost*	1	acre	$282.00	$282.00
*Based on landlord crop-share	25%			
Overhead[2]				$9.79
Management Fee[3]				$19.00
Total Ownership Costs				$345.99
Ownership Costs per Unit				$3.68
Total Costs per Acre				$548.55
Total Cost per Unit				$5.84
Returns to Risk				**$579.45**

Production Costs for CS2-YR2, Organic Winter Pea Hay				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Winter Pea hay	0.9	bu	$200.00	$180.00
Variable Inputs				
Seed:				$120.00
Winter Pea - Windham	200	lb	$0.60	$120.00
Machinery:				$68.30
Fuel	8.23	gal	$3.40	$27.97
Lubricants	1	acre	$4.18	$4.18
Machinery Repairs	1	acre	$10.98	$10.98
Machinery Labor	1.26	hour	$20.00	$25.17
Other:				$33.00
Crop Insurance	1	acre	$9.00	$9.00
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	acre	$20.00	$20.00
Operating Interest[1]				$7.75
Total Variable Costs				$229.05
Variable Costs per Unit				$254.50
Net Returns Above Operating Expenses				**-$49.05**
Ownership (Fixed) Costs:				
Machinery depreciation			$19.05	$19.05
Machinery interest			$10.97	$10.97
Machinery insurance, taxes housing, licence			$3.78	$3.78
Land Cost*	1	acre	$45.00	$45.00
*Based on landlord crop-share	25%			
Overhead[2]				$11.07
Management Fee[3]				$19.00
Total Ownership Costs				$108.87
Total Costs per Acre				$337.91
Returns to Risk				**-$157.91**

Production Costs for CS3-YY1, Organic Winter Pea Green Manure				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Winter Pea Green Manure	0	bu	$0.00	$0.00
Variable Inputs				
Seed:				$120.00
Winter Pea - Windham	200	lb	$0.60	$120.00
Machinery:				$25.40
Fuel	6.50	gal	$3.40	$22.09
Lubricants	1	acre	$3.31	$3.31
Machinery Repairs	1	acre	$7.71	$7.71
Machinery Labor	0.99	hour	$20.00	$19.89
Other:				$4.00
Crop Insurance	1	acre	$0.00	$0.00
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$5.23
Total Variable Costs				$197.00
Net Returns Above Operating Expenses				**-$197.00**
Ownership (Fixed) Costs:				
Machinery depreciation			$13.41	$13.41
Machinery interest			$8.30	$8.30
Machinery insurance, taxes housing, license			$2.77	$2.77
Land Cost[4]	1	acre	$60.00	$60.00
Land tax				$5.50
Overhead[2]				$7.47
Management Fee[3]				$19.00
Total Ownership Costs				$116.45
Total Costs per Acre				$313.45
Returns to Risk				**-$313.45**

[4] $1500/ac land value with 4% return on investment

Production Costs for CS3-YR2, Organic Soft White Winter Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$466.49
Soft white winter wheat	39	bu	$13.00	$507.00
Dockage	7.99%			-$40.51
Variable Inputs				
Seed:				$35.10
Winter Wheat - Brundage	135	lb	$0.26	$35.10
Machinery:				$53.03
Fuel	5.48	gal	$3.40	$18.65
Lubricants	1	acre	$2.79	$2.79
Machinery Repairs	1	acre	$11.42	$11.42
Machinery Labor	1.01	hour	$20.00	$20.17
Other:				$28.50
Crop Insurance	1	acre	$4.50	$4.50
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$4.08
Total Variable Costs				$120.71
Variable Costs per Unit				$3.10
Net Returns Above Operating Expenses				**$386.29**
Ownership (Fixed) Costs:				
Machinery depreciation			$17.79	$17.79
Machinery interest			$11.27	$11.27
Machinery insurance, taxes housing, license			$5.31	$5.31
Amortized Green Manure costs				$335.39
Land Cost*	1	acre	$126.75	$126.75
*Based on landlord crop-share	25%			
Overhead[2]				$29.43
Management Fee[3]				$35.00
Total Ownership Costs				$560.94
Ownership Costs per Unit				$14.38
Total Costs per Acre				$681.65
Total Cost per Unit				$17.48
Returns to Risk				**-$174.65**

Production Costs for CS4-YR1, Organic Hard Red Spring Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$515.22
Hard Red Spring Wheat	33	bu	$16.00	$528.00
Dockage	2.42%			-$12.78
Variable Inputs				
Seed:				$79.80
Hard Red Spring Wheat - Kelse	140	lb	$0.57	$79.80
Fertilizer:				$93.70
Manure or organic fertilizer	2.2	ton	$18.00	$39.22
Hauling Manure (150 miles)		ton	$25.00	$54.48
Machinery:				$62.73
Fuel	6.72	gal	$3.40	$22.85
Lubricants	1	acre	$3.42	$3.42
Machinery Repairs	1	acre	$13.57	$13.57
Machinery Labor	1.14	hour	$20.00	$22.89
Other:				$31.50
Crop Insurance	1	acre	$7.50	$7.50
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$9.37
Total Variable Costs				$277.10
Variable Costs per Unit				$8.40
Net Returns Above Operating Expenses				**$250.90**
Ownership (Fixed) Costs:				
Machinery depreciation			$22.15	$22.15
Machinery interest			$14.19	$14.19
Machinery insurance, taxes housing, license			$5.68	$5.68
Land Cost*	1	acre	$132.00	$132.00
*Based on landlord crop-share	25%			
Overhead[2]				$13.39
Management Fee[3]				$30.00
Total Ownership Costs				$217.41
Ownership Costs per Unit				$6.59
Total Costs per Acre				$494.50
Total Cost per Unit				$14.98
Returns to Risk				**$33.50**

Production Costs for CS4-YR2, Organic Winter Pea Hay				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Winter Pea hay	1.2	bu	$200.00	$240.00
Variabl Inputs				
Seed:				$120.00
Winter Pea - Windham	200	lb	$0.60	$120.00
Machinery:				$60.02
Fuel	7.07	gal	$3.40	$24.03
Lubricants	1	acre	$3.59	$3.59
Machinery Repairs	1	acre	$9.84	$9.84
Machinery Labor	1.13	hour	$20.00	$22.56
Other:				$33.00
Crop Insurance	1	acre	$9.00	$9.00
Organic Certification	1	acre	$4.00	$4.00
Organic administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$7.46
Total Variable Costs				$220.48
Variable Costs per Unit				$183.73
Net Returns Above Operating Expenses				**$19.52**
Ownership (Fixed) Costs:				
Machinery depreciation			$17.05	$17.05
Machinery interest			$9.69	$9.69
Machinery insurance, taxes housing, license			$3.49	$3.49
Land Cost*	1	acre	$60.00	$60.00
*Based on landlord crop-share	25%			
Overhead[2]				$10.65
Management Fee[3]				$19.00
Total Ownership Costs				$119.88
Total Costs per Acre				$340.36
Returns to Risk				**-$100.36**

Production Costs for CS4-YR3, Organic Soft White Winter Wheat

Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$1,046.90
Soft white winter wheat	84	bu	$13.00	$1,092.00
Dockage	4.13%			-$45.10
Variable Inputs				
Seed:				$35.10
Winter wheat - Brundage	135	lb	$0.26	$35.10
Fertilizer:				$86.00
Manure or organic fertilizer	2.0	ton	$18.00	$36.00
Hauling Manure (150 miles)		ton	$25.00	$50.00
Machinery:				$54.60
Fuel	5.68	gal	$3.40	$19.32
Lubricants	1	acre	$2.89	$2.89
Machinery Repairs	1	acre	$11.89	$11.89
Machinery Labor	1.03	hour	$20.00	$20.50
Other:				$28.50
Crop Insurance	1	acre	$4.50	$4.50
Organic Certification	1	acre	$4.00	$4.00
Organic Administrative labor	1	hour	$20.00	$20.00
Operating Interest[1]				$7.15
Total Variable Costs				$211.35
Variable Costs per Unit				$2.52
Net Returns Above Operating Expenses				**$880.65**
Ownership (Fixed) Costs:				
Machinery depreciation			$18.29	$18.29
Machinery interest			$11.56	$11.56
Machinery insurance, taxes housing, license			$5.35	$5.35
Land Cost*	1	acre	$273.00	$273.00
*Based on landlord crop-share	25%			
Overhead[2]				$10.21
Management Fee[3]				$35.00
Total Ownership Costs				$353.41
Ownership Costs per Unit				$4.21
Total Costs per Acre				$564.76
Total Cost per Unit				$6.72
Returns to Risk				**$527.24**

Production Costs for CS5-YR1, Conventional Hard Red Spring Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$460.52
Hard Red Spring Wheat (DNSW)	58	bu	$8.00	$464.00
Dockage	0.75%			-$3.48
Variable Inputs				
Seed:				$30.00
Hard Red Spring Wheat (DNSW)	100	lb	$0.30	$30.00
Fertilizer:				$108.30
Nitrogen (dry)	130	lb	$0.70	$91.00
Phosphorous (dry)	5	lb	$0.66	$3.30
Potassium (dry)	0	lb	$0.36	$0.00
Sulfur (dry)	25	lb	$0.56	$14.00
Herbicide:				$27.06
Glyphosate	36	oz	$0.19	$6.84
M90	3	oz	$0.17	$0.51
Ammonium Sulfate	1.7	lb	$0.35	$0.60
Axial	8.2	oz	$1.14	$9.35
Brox M	12	oz	$0.27	$3.24
Starane	8	oz	$0.50	$4.00
InPlace	5	oz	$0.28	$1.40
Ammonium Sulfate	3.2	oz	$0.35	$1.12
Fungicides:				$22.03
Quilt	14	oz	$1.35	$18.90
Syltac Sticker	0.5	pt	$6.25	$3.13
Machinery:				$49.23
Fuel	5.09	gal	$3.40	$17.30
Lubricants	1	acre	$2.59	$2.59
Machinery Repairs	1	acre	$10.04	$10.04
Machinery Labor	0.97	hour	$20.00	$19.30
Custom & Consultants:				$8.95
Custom Aerial	1	acre	$8.95	$8.95
Other:				$7.00
Crop Insurance	1	acre	$7.00	$7.00
Operating Interest[1]				$7.76
Total Variable Costs				$260.32
Variable Costs per Unit				$4.49
Net Returns Above Operating Expenses				**$203.68**

(CS5-YR1 cont).

Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Ownership (Fixed) Costs:				
Machinery depreciation			$14.48	$14.48
Machinery interest			$9.05	$9.05
Machinery insurance, taxes housing, license			$5.06	$5.06
Land Cost*	1	acre	$116.00	$116.00
*Based on landlord crop-share	25%			
Overhead[2]				$8.23
Management Fee				$22.00
Total Ownership Costs				$174.82
Ownership Costs per Unit				$3.01
Total Costs per Acre				$435.14
Total Cost per Unit				$7.50
Returns to Risk				**$28.86**

Production Costs for CS5-YR2, Conventional Winter Pea Hay				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Winter Pea hay	0.44	bu	$200.00	$88.00
Variable Inputs				
Seed:				$120.00
Winter Pea - Windham	200	lb	$0.60	$120.00
Herbicide:				$7.92
Assure II EC	10	oz	$0.69	$6.90
Crop oil concentrate	12.8	0z	$0.08	$1.02
Machinery:				$53.49
Fuel	6.28	gal	$3.40	$21.36
Lubricants	1	acre	$3.20	$3.20
Machinery Repairs	1	acre	$8.28	$8.28
Machinery Labor	1.03	hour	$20.00	$20.65
Other:				$9.00
Crop Insurance	1	acre	$9.00	$9.00
Operating Interest[1]				$6.39
Total Variable Costs				$196.80
Variable Costs per Unit				
Net Returns Above Operating Expenses				**-$108.80**
Ownership (Fixed) Costs:				
Machinery depreciation			$13.43	$13.43
Machinery interest			$7.22	$7.22
Machinery insurance, taxes housing, license			$3.19	$3.19
Land Cost*	1	acre	$22.00	$22.00
*Based on landlord crop-share	25%			
Overhead[2]				$9.12
Management Fee				$14.00
Total Ownership Costs				$68.96
Total Costs per Acre				$265.77
Returns to Risk				**-$177.77**

Production Costs for CS5-YR3, Conventional Soft White Winter Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Soft white winter wheat	80	bu	$6.50	$520.00
Variable Inputs				
Seed:				$25.20
Winter wheat	90	lb	$0.28	$25.20
Fertilizer:				$88.70
Nitrogen (dry)	110	lb	$0.70	$77.00
Phosphorous (dry)	5	lb	$0.66	$3.30
Sulfur (dry)	15	lb	$0.56	$8.40
Herbicide:				$38.25
Glyphosate	36.00	oz	$0.19	$6.84
Ammonium Sulfate	3.40	lb	$0.35	$1.19
M90	3.00	oz	$0.17	$0.51
Osprey	4.75	oz	$3.70	$17.58
Starane+Salvo	22.00	oz	$0.50	$11.00
R-11	3.20	oz	$0.22	$0.70
Brox M	1.60	oz	$0.27	$0.43
Fungicides:				$22.03
Quilt	14	oz	$1.35	$18.90
Syltac Sticker	0.5	pt	$6.25	$3.13
Machinery:				$49.23
Fuel	5.09	gal	$3.40	$17.30
Lubricants	1	acre	$2.59	$2.59
Machinery Repairs	1	acre	$10.04	$10.04
Machinery Labor	0.97	hour	$20.00	$19.30
Custom & Consultants:				$8.95
Custom Aerial	1	acre	$8.95	$8.95
Other:				$4.50
Crop Insurance	1	acre	$4.50	$4.50
Operating Interest[1]				$8.29
Total Variable Costs				$245.15
Variable Costs per Unit				$3.06
Net Returns Above Operating Expenses				**$274.85**

(CS5-YR3 cont.)

Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Ownership (Fixed) Costs:				
Machinery depreciation			$14.48	$14.48
Machinery interest			$9.05	$9.05
Machinery insurance, taxes housing, license			$5.06	$5.06
Land Cost*	1	acre	$130.00	$130.00
*Based on landlord crop-share	25%			
Overhead[2]				$7.80
Management Fee				$26.00
Total Ownership Costs				$192.39
Ownership Costs per Unit				$2.40
Total Costs per Acre				$437.53
Total Cost per Unit				$5.47
Returns to Risk				**$82.47**

Production Costs for CS6-YR1, Conventional Hard Red Spring Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$460.52
Hard Red Spring Wheat (DNSW)	58	bu	$8.00	$464.00
Dockage	0.75%			-$3.48
Variable Inputs				
Seed:				$30.00
Hard Red Spring Wheat (DNSW)	100	lb	$0.30	$30.00
Fertilizer:				$108.30
Nitrogen (dry)	130	lb	$0.70	$91.00
Phosphorous (dry)	5	lb	$0.66	$3.30
Potassium (dry)	0	lb	$0.36	$0.00
Sulfur (dry)	25	lb	$0.56	$14.00
Herbicide:				$27.06
Glyphosate	36	oz	$0.19	$6.84
M90	3	oz	$0.17	$0.51
Ammonium Sulfate	1.7	lb	$0.35	$0.60
Axial	8.2	oz	$1.14	$9.35
Brox M	12	oz	$0.27	$3.24
Starane	8	oz	$0.50	$4.00
InPlace	5	oz	$0.28	$1.40
Ammonium Sulfate	3.2	oz	$0.35	$1.12
Fungicides:				$22.03
Quilt	14	oz	$1.35	$18.90
Syltac Sticker	0.5	pt	$6.25	$3.13
Machinery:				$49.23
Fuel	5.09	gal	$3.40	$17.30
Lubricants	1	acre	$2.59	$2.59
Machinery Repairs	1	acre	$10.04	$10.04
Machinery Labor	0.97	hour	$20.00	$19.30
Custom & Consultants:				$8.95
Custom Aerial	1	acre	$8.95	$8.95
Other:				$7.00
Crop Insurance	1	acre	$7.00	$7.00
Operating Interest[1]				$7.76
Total Variable Costs				$260.32
Variable Costs per Unit				$4.49
Net Returns Above Operating Expenses				**$203.68**

(CS6-YR1 cont).

Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Ownership (Fixed) Costs:				
Machinery depreciation			$14.48	$14.48
Machinery interest			$9.05	$9.05
Machinery insurance, taxes housing, license			$5.06	$5.06
Land Cost*	1	acre	$116.00	$116.00
*Based on landlord crop-share	25%			
Overhead[2]				$8.23
Management Fee				$22.00
Total Ownership Costs				$174.82
Ownership Costs per Unit				$3.01
Total Costs per Acre				$435.14
Total Cost per Unit				$7.50
Returns to Risk				**$28.86**

Production Costs for CS6-YR2, Conventional Spring Pea				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				$243.00
Spring Pea	1800	lb	$0.14	$243.00
Variable Inputs				
Seed:				$54.00
Spring Pea - Aragorn	200	lb	$0.27	$54.00
Herbicide:				$42.36
Glyphosate	36	oz	$0.19	$6.84
Pursuit	3	oz	$3.45	$10.35
Prowl	24	oz	$0.34	$8.16
Ammonium Sulfate	6.25	pt	$0.35	$2.19
M90	3	oz	$0.17	$0.51
Imidan 70	1	lb	$12.70	$12.70
Dimethoate	0.33	pt	$4.88	$1.61
Machinery:				$46.57
Fuel	4.70	gal	$3.40	$15.99
Lubricants	1	acre	$2.39	$2.39
Machinery Repairs	1	acre	$9.12	$9.12
Machinery Labor	0.95	hour	$20.00	$19.07
Other:				$7.00
Crop Insurance	1	acre	$7.00	$7.00
Operating Interest[1]				$5.25
Total Variable Costs				$155.18
Variable Costs per Unit				$0.09
Net Returns Above Operating Expenses				**$87.82**
Ownership (Fixed) Costs:				
Machinery depreciation			$13.67	$13.67
Machinery interest			$8.53	$8.53
Machinery insurance, taxes housing, license			$4.96	$4.96
Land Cost*	1	acre	$60.75	$60.75
*Based on landlord crop-share	25%			
Overhead[2]				$2.68
Management Fee				$13.00
Total Ownership Costs				$103.59
Ownership Costs per Unit				$0.06
Total Costs per Acre				$258.76
Total Cost per Unit				$0.14
Returns to Risk				**-$15.76**

Production Costs for CS6-YR3, Conventional Soft White Winter Wheat				
Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Gross Returns				
Soft white winter wheat	80	bu	$6.50	$520.00
Variable Inputs				
Seed:				$25.20
Winter wheat	90	lb	$0.28	$25.20
Fertilizer:				$88.70
Nitrogen (dry)	110	lb	$0.70	$77.00
Phosphorous (dry)	5	lb	$0.66	$3.30
Sulfur (dry)	15	lb	$0.56	$8.40
Herbicide:				$38.25
Glyphosate	36.00	oz	$0.19	$6.84
Ammonium Sulfate	3.40	lb	$0.35	$1.19
M90	3.00	oz	$0.17	$0.51
Osprey	4.75	oz	$3.70	$17.58
Starane+Salvo	22.00	oz	$0.50	$11.00
R-11	3.20	oz	$0.22	$0.70
Brox M	1.60	oz	$0.27	$0.43
Fungicides:				$22.03
Quilt	14	oz	$1.35	$18.90
Syltac Sticker	0.5	pt	$6.25	$3.13
Machinery:				$49.23
Fuel	5.09	gal	$3.40	$17.30
Lubricants	1	acre	$2.59	$2.59
Machinery Repairs	1	acre	$10.04	$10.04
Machinery Labor	0.97	hour	$20.00	$19.30
Custom & Consultants:				$8.95
Custom Aerial	1	acre	$8.95	$8.95
Other:				$4.50
Crop Insurance	1	acre	$4.50	$4.50
Operating Interest[1]				$8.29
Total Variable Costs				$245.15
Variable Costs per Unit				$3.06
Net Returns Above Operating Expenses				**$274.85**

(CS6-YR3 cont.)

Item	Quantity Per Acre	Unit	Price or Cost	Value or Cost/Acre
Ownership (Fixed) Costs:				
Machinery depreciation			$14.48	$14.48
Machinery interest			$9.05	$9.05
Machinery insurance, taxes housing, license			$5.06	$5.06
Land Cost*	1	acre	$130.00	$130.00
*Based on landlord crop-share	25%			
Overhead[2]				$7.80
Management Fee				$26.00
Total Ownership Costs				$192.39
Ownership Costs per Unit				$2.40
Total Costs per Acre				$437.53
Total Cost per Unit				$5.47
Returns to Risk				**$82.47**