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Exploring Organic Grain and Forage Production As a Profitable Enterprise for Palouse Farmers

Contents

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Introduction

FOR GROWERS IN THE SEMIARID Palouse agricultural region of eastern Washington and northern Idaho, there are few crop alternatives that rival the profit potential of wheat (Schillinger et al. 2010). However, the high productive capacity of wheat has been coupled with historically high rates of soil erosion, which remains an underlying concern for growers throughout this region. Many farms have adopted conservation and reduced-tillage practices to mitigate risks of erosion and have diversified production by including crops such as canola, garbanzo beans, spring peas, and barley in wheat-based rotations. Inclusion of these alternative crops extends crop rotations, which can reduce weed and pest pressure and diversify sources of farm income. Organic crop production is another alternative for diversifying farm income that is not common on Palouse wheat farms, despite potential benefits to improve soil health, including increased soil carbon and soil biological activity (Reganold 1988; Mäder et al. 2002; Wachter et al. 2019) and opportunities for price premiums. However, organic farming systems often use tillage for weed control, and given the high risk of soil erosion in the Palouse, the common use of tillage in organic systems is a significant barrier to adopting organic management practices in this region.

There is little information about organic grain production in the Palouse, likely because it accounts for such a small portion of total crop production. For instance, the 2012 Census of Agriculture reported that 0.1% of harvested wheat acres in Washington State were produced organically; in Idaho 0.8% and Oregon 0.3% of wheat acres harvested were organic (United States Department of Agriculture-National Agricultural Statistics Service [USDA-NASS] 2014a and 2014b). Some organic crops grown in the Pacific Northwest are produced on a small number of acres within larger conventional farms (Lorent et al. 2016), which helps reduce risk. Globally, organic grain yields are often lower than conventional yields (Seufert et al. 2012); however, trade-offs exist in terms of lower input costs, organic price premiums, and long-term gains in soil health, which suggest potential for agronomic and economic benefits of incorporating organic practices into Palouse grain farms.

Increased demand for organic grains, driven by the rapid expansion of the organic livestock industry and need for organic feed sources, has outpaced organic grain production in the United States in recent years. Between 2008 and 2016, US land area planted to organic corn, soybeans, wheat, oats, and barley grew by 22% (626,000 acres increased to 765,000 acres), whereas the value of organic livestock production grew by 300% ($1.2 billion increased to $3.3 billion). Imported organic grains have increased during this time period, as domestic supply did not meet demand, and in 2015 the value of imported organic grains exceeded the value of domestically grown organic grain (Reaves et al. 2019). Greater demand for domestic organic grain than what US farms are currently supplying suggests potential market opportunities, and few farms in the Pacific Northwest are pursuing it.

Research suggests there is potential for organic grain and forage production systems to be a profitable niche enterprise within a traditional Palouse nonorganic wheat farm. Economic sustainability for organic cropping systems exists when potentially lower and more variable yields are balanced with lower costs of production, price premiums, and improvements to soil health properties (Wachter et al. 2019). The availability of organic price premiums is integral to the profitability of organic cropping systems—they offset some of the risk associated with lower and more variable yields in organic production. However, to avoid overreliance on premiums, those producers wanting to transition to sustainable organic production in this region will need to develop agronomic strategies that can achieve competitive organic crop yields while meeting regional soil health and conservation needs.

The initial three-year transition period needed to obtain organic certification presents a primary economic obstacle for growers (Reaves et al. 2019). Crops produced during this period must be grown without synthetic fertilizers or chemical pesticides but are not eligible for organic price premiums. Other obstacles perceived by growers include risks associated with lower and variable yields, access to markets for organic grains (Jones et al. 2006), a need for on-farm storage of organic grain to offset lack of organic-specific storage in regional storage infrastructure, greater managerial time requirements for certification (McBride et al. 2015), and a lack of research and Extension technical assistance specific to organic management (Reaves et al. 2019). These challenges are significant, and while there are resources and research available to help inform and support organic crop production, a centralized, easily accessible location does not yet exist, which limits the usefulness of these resources for growers (Reaves et al. 2019). Moreover, regionally specific economic analyses of organic production systems are important to help growers assess the risks and feasibility of adopting these practices. Unfortunately, they are not always available.

Although there is economic potential in organic grain production, there are significant agronomic challenges to overcome. Effective weed control is one of the top agronomic barriers perceived by wheat growers because of the lack of herbicides certified for use in organic production (Jones et al. 2006; McBride et al. 2015). Moreover, the hilly landscape of the Palouse further exacerbates the risk of erosion associated with using tillage to manage weeds, which is a common weed management practice among organic producers. Thus, methods for reducing tillage and erosion are critical for integrating organic production into Palouse wheat-cropping systems. Research in the Palouse suggests that organic weed control can be achieved with shallow-disturbance tillage equipment, such as the rotary harrow and hoe, in combination with traditional methods, like growing crops that are competitive with weeds (Figure 1).

Growers in both organic and nonorganic farming systems are experimenting with cover crops for weed control, soil fertility, and other soil health benefits, although results of cover crop research in the Palouse are still preliminary. Including organic hay crops within small grain rotations also shows promise as a useful tool for weed management

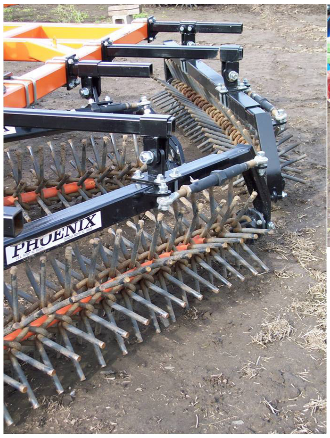

Figure 1. Shallow disturbance implements used for weed control and crop termination. Left: Rotary harrow. Above: Rotary hoe.

(Tautges et al. 2016a). Hay cuttings followed by repeated mowing to suppress subsequent weed growth can help reduce weed seed production and reduce weed pressure over time. Using reduced-tillage implements and growing a diverse rotation of crops that are competitive with weeds may help overcome important agronomic and soil conservation challenges associated with organic field crop management in the Palouse.

Managing soil fertility in organic systems is another significant barrier to adoption because there are few locally available animal manure sources or certified organic fertilizer resources in the Palouse. Moreover, legume cover crops that could provide some of the nitrogen (N) required for grain production are difficult to establish under the limited moisture conditions in the region without sacrificing a year of cash crop production to grow the cover crop. Indeed, fertilizer applications may be crucial to obtaining sufficient N levels to support high grain yields, as research in the region has found that legumes alone do not add enough available N to achieve yields that are economically viable (defined as positive returns to total costs) in the Palouse climate (Tautges et al. 2018). Chicken and cattle manure sources do exist in the area, but transportation costs may be prohibitive, depending on proximity to these sources. Despite limitations on organic fertilizer resources, the small number of growers in the Pacific Northwest who produce organic crops are able to obtain organic fertilizer resources, including blood meal, pelletized chicken manure, raw manure, fish fertilizers, and foliar sprays, or have developed systems that rely more heavily on legume cover crops to maintain soil fertility (Lorent et al. 2016).

Including forage or legume hay crops in small grain crop rotations is a strategy for managing both weeds and soil fertility. Moreover, hay can be a profitable crop in organic rotations, in part because of low input costs (Wachter et al. 2019). While there are few large livestock operations in the Palouse, there are small local operations as well as larger-scale livestock markets in the greater Pacific Northwest region. When hay markets are available, including legume hay crops in rotations can be a good strategy to reduce the overall rotational fertilizer requirements while offering weed-control opportunities. As a consequence of inadequate soil fertility, poor grain quality and low yields are a concern in organic production systems. However, a study of dryland organic grain crop rotations in the Pacific Northwest shows that yield, test weight, and protein levels can be attainable at levels comparable to conventional wheat when animal manure fertilizer is used (Park et al. 2015). Wheat that does not meet food-grade quality standards can be sold for animal feed. However, the present study focuses on the economic viability of food-grade organic wheat production.

The goals of this study are twofold: to leverage recent field trial data for organic crop productivity under reduced-tillage conditions in the Palouse with the costs of production and price data in order to estimate the farm-scale profitability of realistically adoptable organic production systems; and to describe the principal factors that determine profitability within the systems.

Background: Organic Price Trends and Production Costs

While organic premiums fluctuate through time, they have remained relatively stable for wheat in recent years. From 1996 to 2006 organic wheat prices ranged from 1.2 to 2 times higher than conventional prices (Dimitri and Oberholtzer 2009). From 2011 to 2018, average organic wheat prices remained stable and were approximately $10 per bushel (bu) or higher. For example, in 2016 organic wheat prices were approximately 2.5 times higher than conventional prices (Reaves et al. 2019; USDA-NASS 2019). By contrast, conventional farmgate wheat prices have fluctuated greatly over the last few decades, with the price dropping to $5.50/bu or lower in 2015. In recent years, conventional wheat prices have remained relatively low regionally. The national season average for all classes of wheat at the end of 2019 was $4.60 per bu (USDA 2019). Between 2010 and 2014, organic barley prices ranged from $5 to $11 per bu and averaged approximately 1.5 times higher than conventional prices between 2011 and 2016.

The price premium for organic wheat depends on its type and quality. For instance, between 2011 and 2014, organic feed-grade hard red (HR) wheat prices tended to be lower ($8.50–$15 per bu) than organic food-grade HR wheat prices ($8.50–$20 per bu). Although both food- and feed-grade organic wheat remained higher than conventional prices during this same period ($6–$8.50 per bu), organic feed-grade HR wheat prices are not always high enough to cover operating costs (McBride et al. 2015). Moreover, organic HR wheat prices tend to be higher than prices for organic soft white wheat. For instance, 2014 average organic food-grade wheat prices were $21 per bu for HR spring, $16 per bu for HR winter, and $14 per bu for soft white (www.mercaris.com). Prices have fallen in recent years, with HR winter wheat averaging $14 per bu in early 2019 (Sterk 2019).

Organic premiums are typically needed for organic production to be economically competitive with conventional production. Average operating costs per acre are similar for organic and conventional wheat production in the western United States, though costs are distributed differently (McBride et al. 2015). Lower fertilizer costs and no chemical pesticide costs in organic wheat production are offset by higher seed, fuel, and repair costs. However, average operating costs and total economic costs per bushel are higher for organic systems, the result of lower yields per acre and higher land, capital, and labor costs (McBride et al. 2015). Price premiums for organic food-grade wheat have been generally high enough to compensate for higher organic production costs, but to our knowledge there are no farm-scale analyses of operating costs and profitability for dryland organic grain production that are specific to the Pacific Northwest. Plot-scale research in the Palouse reports that organic mixed crop–livestock rotations can be profitable without organic premiums (Wachter et al. 2019), suggesting further investigation of organic mixed crop–livestock systems at the field scale is merited for this region. More broadly, integrating livestock production into grain-dominated agricultural regions, such as the Palouse, could be mutually beneficial to both grain and crop production systems. The present study includes organic grain-hay crop rotations but does not include livestock explicitly.

While the greater Pacific Northwest has a vibrant hay market, including for export, hay markets are limited within the Palouse region. Organic hay prices vary depending on the size of bales and quality of the hay, and sometimes size dictates price more than quality due to end-use demand. For example, in 2018, national organic hay prices ranged between $170 per ton for “Good”-quality midsquares and $260 per ton for “Fair”-quality large squares. Organic hay can be a profitable crop to include in organic rotations, depending on local demand.

There are two ways in which this study expands on the literature cited above. First, the existing literature on costs of production for organic grain are estimated based on different climate regions and traditional tillage practices that are not feasible in the Palouse due to erosion concerns. This study provides estimates of field-scale costs of production under more realistic reduced-tillage production systems. Second, due to their plausible agronomic benefits, various forages are included in the crop rotations for reduced-tillage cropping systems to determine how their inclusion influences estimated profitability.

Finally, this study was conducted in the high rainfall area of the Palouse where precipitation is sufficient to support annual dryland crop production. In drier regions of the Pacific Northwest where fallow is included in rotations, expected yields and cost of production would differ. However, there are growers in drier regions who are growing organic grains and forages using similar crop rotations but with fallow included. For more information about organic production practices in lower rainfall zones, see Lorent et al. (2016).

Palouse Organic Reduced-Tillage Research

Organic reduced-tillage (ORT) crop production research trials began in 2003 at the Boyd Farm near Pullman, Washington, with a five-year study examining the three-year transition to organic production, followed by two years of certified organic wheat production in 2006 and 2007 (Gallagher et al. 2010; Borrelli et al. 2015). In 2008, the plots were converted to new ORT crop rotations based on lessons learned during the transition study. Five organic cropping systems were arranged in a complete randomized block design (including five replications) in 30 × 50 ft plots on a west-facing slope with deep silt-loam soil (Palouse Soil Series). In this study, organic reduced-tillage systems with manure fertilizer and perennial and green manure legumes in rotation increased soil organic carbon and soil biological activity, compared to typical nonorganic, no-till practices (Tautges et al. 2016b). Yield and field operations used in the Boyd ORT trial from 2009 to 2013 were used to evaluate the economic viability of Palouse ORT cropping systems during early to midproduction years of certified organic grain and forage production. The climate at this site is Mediterranean with cool, moist winters and hot, dry summers, where about 60% of precipitation occurs during winter months. Average annual rainfall was 15 inches during the years of this study (2008–13).

Understanding the risk of soil erosion in ORT systems is important for considering adoption of these practices in the Palouse. While soil erosion was not measured directly in the Boyd ORT Trial, Soil Tillage Intensity Rating (STIR) values developed by the Natural Resource Conservation Service (NRCS) for use in modeling soil erosion were used to estimate potential risk of erosion in the Boyd ORT cropping systems. The STIR system assigns a value to all field operations based on the soil disturbance they cause. Values are summed for each crop per rotation and averaged for each crop rotation. Low STIR values indicate less risk of erosion. The NRCS defines no-till systems as having STIR values of 30 or less and conservation tillage systems as having values of 60 or less (USDA-NRCS 2008).

To evaluate economic viability, we applied the results from the Boyd ORT trial to a split-farm model. Split-farm adoption is a path that conventional growers have taken in the Pacific Northwest and other parts of the United States for experimenting with organic production. This approach shares the expense of intensive field management and specialized farm machinery needed for organic production with farm operations that also include less management-intensive, nonorganic production. Also, until the risk of soil erosion in ORT systems is evaluated further, the split-farm model could allow growers to implement these systems on land that is less prone to erosion (i.e., flatter areas). Starting small reduces the risk of committing an entire farm to an alternative cropping strategy while also achieving economies of scale with respect to farm machinery costs.

Methods

Economic Analysis and an Online Enterprise Budget Tool

Enterprise budgets for each cropping system were developed to assess components of production as well as compare whole cropping-system profitability at the field scale. Enterprise budgets are useful for this purpose because they clearly itemize all revenue and cost factors, which helps identify the strengths and weaknesses of the system and allows for sensitivity analysis.

For the organic enterprise budgets, we assumed that approximately 5% of a farm's production is certified organic—in this case 100 acres within a 2,000-acre farm. Machinery costs are shared between organic and conventional crop production. Time requirements for separating and cleaning organic and nonorganic equipment and materials to meet organic certification standards are included in labor costs.

Machine operations, input costs, and expected yields of the organic cropping systems represent field operations used in the Boyd ORT trial. Data were collected from 30 × 50 ft plots and scaled to per-acre values. Machinery costs were calculated for typical conventional farm-size equipment based on the use of plot-size equipment used in the study. Quail manure containing an average of 5.7% total nitrogen

(TN) was used as fertilizer in the Boyd ORT trial, slightly higher than other common poultry manure sources, which range between 4.1% and 5.1% TN (Bary et al. 2016).

Four ORT cropping systems (CS1, CS2, CS3, CS4) from the Boyd ORT trial were analyzed for economic feasibility, and one conventional, no-till cropping system (CS5), based on regional production factors and yield, served as a comparison to business-as-usual, no-till nonorganic production. While there were two nonorganic no-till cropping systems included as control systems in the Boyd ORT trial, we chose to compare the Boyd ORT systems to more generalized production factors and yield for the region (Painter 2019) due to production problems in the nonorganic trial plots. See Tables 1 and 2 for detailed management practices used in this analysis, including timing and rates of specific inputs, operations, and STIR values. An adjustable Enterprise Budget Tool for individual crops within each rotation is available at https://tinyurl.com/PalouseORTBudgets (Kahl and Painter 2019). This tool allows growers to adjust study assumptions to reflect individual farm scenarios.

The net present value (NPV) of returns over both variable costs and total costs were calculated across the different systems. NPV is used to evaluate investments and is calculated as the difference between cash inflows and outflows over a period of time, adjusted for the time value of money based on a selected discount rate and the length of time of a given crop rotation. A positive NPV indicates that a cropping system is profitable. To compare cropping systems that span different lengths of time (2–5-year rotations in the Boyd ORT systems trials), we calculated average annual returns per acre over time represented as the annual equivalent annuity (AEA) of the NPV of returns over total costs (RTC) for the different systems, which we term annualized economic returns (AER). AER is calculated as

$$r(\mathrm{NPV})/(1 + (1 + r)^{-\mathrm{n}})$$

where r represents the interest rate, NPV the net present value, and n the number of years. Thus, discussions of profitability in this study refer to AER, calculated as AEA of NPV of RTC, and are reported on an annual basis unless noted otherwise. Thus, AER represents the annual profitability of each system and allows comparison of cropping systems that span different lengths of time.

Profitability and Risk Assessment of ORT Cropping Systems

To assess profitability and risk associated with organic crop production, four ORT cropping systems were evaluated with and without organic premiums. While demand is generally high for organic grain crops, access to organic grain buyers may be a challenge because there are few processors and distribution networks are less developed than those for conventional crops. In some instances, a lack of regionally dispersed organic processing facilities and a lack of organic-specific distribution infrastructure can force growers to sell organic crops into conventional markets at lower prices. To assess the sensitivity of profitability to organic premiums, we compared three scenarios: 100%, 50%, or 0% of crop yield sold with current organic premiums. This strategy demonstrates the potential for profitability under different market conditions, allowing growers to assess risk based on the availability of organic premiums or sensitivity to fluctuations in premium values. For instance, analysis of profitability under the 50% organic premium scenario can be viewed as half the crop being sold at a conventional price, or a 50% reduction in the value of organic premiums. To explore other price scenarios, the percent of crop yield sold with organic premiums can be adjusted using the online Enterprise Budget Tool.

Yield uncertainty represents a common area of risk in organic systems. Coefficient of variation (CV) of yields from the Boyd ORT trial was used to assess variability and associated risk within the different crop rotations based on the trial results. CV is calculated as the ratio of the standard deviation to the mean.

Input Costs

A list of farm equipment, value, and usage assumptions is included in Table 1. Input costs were converted to 2019 values using USDA-NASS Quick-Stats survey prices paid (USDA-NASS 2019), using 2013 as the base year (Patterson and Painter 2014). Therefore, costs of inputs used in this analysis

Table 1. 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 and 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
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	
¾-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 2. Inputs and machine operations of four organic, reduced-till cropping systems and one conventional, direct-seed cropping system.

Crop System and STIR	Crop, Seed Variety, and Rate (lb/acre), Fertilizer (unit/acre)	Machinery Operations
Alfalfa-grain: CS1 ALF, ALF, ALF, WW, SB (organic, 5-year) **STIR = 36**	Alfalfa hay mix 'Ladak' alfalfa (12 lb/acre) Potomac Orchardgrass (8 lb/acre)	Sept–Oct: Undercutter, 2x rotary harrow March: Rotary hoe April–May: Undercutter, rotary hoe, undercutter, drill June: Rotary hoe, mow, rotary hoe, flail mow July: Swath, bale Aug–Sept: 2x flail mow
	Alfalfa (2nd yr) --	Sept–Oct: 2x rotary harrow April–May: 3x rotary hoe June: Swath and bale July: Swath and bale Aug–Sept: 2x flail mow
	Alfalfa (3rd yr) --	Sept–Oct: 2x rotary harrow April–May: 3x rotary how June: Swath and bale (mow if necessary for weeds) July: Swath and bale Aug–Sept: Flail mow or undercutter
	Winter Wheat 'Brundage 96' (135 lb/acre)	October: Undercutter, rotary harrow, drill April–May: 3x rotary hoe August: Harvest September: Flail mow
	Spring Barley 'Hesk' (95 lb/acre) 1.0 ton manure/acre (114 lb TN/acre*, 9 lb PAN/acre**)	October: Undercutter, rotary harrow March–April: 2x rotary hoe, 2x undercutter, rotary harrow, spread manure, drill May: Rotary hoe August: Harvest September: Flail mow
Triticale-hay: CS2 TRIT, WP-HAY (organic, 2-year) **STIR = 54**	Winter Triticale 'Trimark336' (135 lb/acre) 2.0 tons manure/acre (228 lb TN/acre, 19 lb PAN/acre)	Sept–Oct: Undercutter, 2x rotary harrow, drill, spread manure April–May: 3x rotary hoe August: Harvest September: Flail mow
	Winter Pea hay 'Windham' (200 lb/acre)	Sept–Oct: Undercutter, 2x rotary harrow, drill April–May: 3x rotary hoe June: Swath and bale July–Sept: 2x flail mow (or undercutter)
Low-input, GM: CS3 WPGM, WW (organic, 2-year) **STIR= 44**	Winter Pea Green Manure 'Windham' (200 lb/acre) (no harvested crop)	Sept–Oct: Undercutter, rotary harrow, drill April–June: 4x rotary hoe June–July: 2x flail mow September: Flail mow (or undercut)
	Winter Wheat 'Brundage 96' (135 lb/acre)	Sept–Oct: Undercutter, rotary harrow, drill April–May: 3x rotary hoe August: Harvest September: Flail mow if necessary

Table 2. (continued) Inputs and machine operations of four organic, reduced-till cropping systems and one conventional, direct-seed cropping system.

Crop System and STIR	Crop, Seed Variety, and Rate (lb/acre), Fertilizer (unit/acre)	Machinery Operations
High-input grain: CS4 SW, WP-HAY, WW (organic, 3-year) **STIR = 44**	HR Spring Wheat 'Kelse' (150 lb/acre) 2.2 tons manure/acre (252 lb TN/acre, 21 lb PAN/acre)	Sept–Oct: Undercutter, rotary harrow March–April: 2x rotary hoe, undercutter, rotary harrow, drill, spread manure May: Rotary hoe Aug–Sept: Harvest, fail mow if necessary
	Winter Pea Hay 'Windham' (200 lb/acre)	Sept–Oct: Undercutter, rotary harrow, drill April–May: 3x rotary hoe June: Swath and bale July: Flail mow August: Undercutter
	Winter Wheat 'Brundage 96' (135 lb/acre) 2.0 tons manure/acre (228 lb TN/acre, 19 lb PAN/acre)	Sept–Oct: Undercutter, rotary harrow, drill, spread manure April–May: 3x rotary hoe August: Harvest September: Flail mow, if necessary for weed control
Conventional[1] comparison: CS5 SW, SP, WW (conventional[1], no-till, 3-year) **STIR = 17**	Dark Northern Spring Wheat (100 lb/acre) (130 lb PAN/acre, 5 lb P, 25 lb S)	March: Spray herbicide April: Drill/fertilize May: Spray herbicide June: Aerial herbicide August: Harvest Sept: Spray herbicide
	Spring Pea (200 lb/acre)	April: Spray herbicide, drill June: Aerial herbicide Aug–Sept: Harvest, spray herbicide
	Winter Wheat (90 lb/acre) (93 lb PAN/acre, 23 lb P, 30 lb K, 9 lb S)	September: Spray herbicide, drill/fertilize April: Spray herbicide June: Aerial herbicide Aug–Sept: Harvest

Notes: ALF = alfalfa-grass mix, GM = green manure, SB = spring barley, SP = spring pea, STIR = Soil Tillage Intensity Rating, SW = spring wheat, TRIT = winter triticale, WPGM = winter pea green manure, WP-HAY = winter pea hay, WW = winter wheat

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, Minn.); the rotary hoe was a 4.5 m M&W 15 MT (MT = minimum tillage)(M and W Gear, Gibson City, Ill.) (Gallagher et al. 2010).

CS5 is based on average production as reported in Painter (2019).

*TN = Total nitrogen. Refers to inorganic (ammonium and nitrate) and organic forms of N in quail manure fertilizer.

**PAN = Plant-available N. Refers to inorganic nitrogen in the forms of ammonium and nitrate in quail manure fertilizer.

[1]Conventional = Refers to management that uses synthetic fertilizers and nonorganic pesticides.

represent 2019 market values. Most input costs can also be adjusted to reflect specific farm or market characteristics.

Land costs. Land rent was calculated based on a 25% crop-share agreement. Crop-share agreements are a traditional land rental agreement in which operators and landowners share risk associated with production and crop prices. Here we assumed that the landlord received a payment equivalent to 25% of the crop value and was not responsible for operating costs.

Organic certification costs. Certification costs vary in price and structure by state. In Idaho, the application fee is based on gross organic sales from the previous year. Annual inspection fees are $35 per hour for the inspector's time plus a travel reimbursement of $0.535 per mile (ISDA 2020). In Washington, the initial certification fee is $375 plus a $375 inspection fee. Renewal application fees in successive years are on a sliding scale based on sales (WSDA 2020). We assume an average annual certification fee of $500 for certification of 100 acres in these budgets as an estimate, recognizing there can be considerable variability in these fees. Currently, there are national cost-share programs available through the USDA that reimburse growers for up to 75% of certification costs. More information is available through state organic certification offices.

Additional administrative time required to manage the certification process is assumed to be one hour per acre annually and is itemized under certification costs in the budgets. This assumption is higher than the estimate provided by a regional organic wheat grower but lower than the average reported in a survey of western US organic wheat farmers of 2.5 hours per acre (McBride et al. 2012). Administrative time per acre would likely decrease with increasing acreage.

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. Regional budgets for conventional crop production currently use a 5% rate, but a 7% rate is closer to the historical average.

Crop insurance. Crop insurance values listed in the budgets are 2019 estimates produced using the USDA Risk Management Agency Quick Premium Calculator. Crop insurance rates are based on yield protection for Idaho organic dryland crops, assuming 75% coverage for forage crops and 85% coverage for grain crops. Organic crop insurance coverage has continued to evolve and expand to new crops over the past several years. Organic contract prices are now available for purchasing crop insurance for approximately 60 commodity crops, and include wheat, barley, and forage production. When premium organic price elections are not available, price elections and insurance payouts are based on conventional prices.

Variable costs. Variable costs including seeds, fertilizer, pesticides, labor, and machine operations are listed in the online Enterprise Budget Tool and compared by category. These are some of the main factors of production that differentiate ORT from conventional no-till practices. For example, organic seeds and fertilizer can be more expensive, but there are no pesticide costs. Also, labor and machine operation costs can be higher in the ORT systems compared to conventional no-till. Labor is valued at $23.76 per hour in this analysis and is included in machine operation costs. One additional hour of labor per acre is included for all organic crops to account for the additional management time required for organic production.

Crop Rotations

CS1—Organic 5-year rotation, alfalfa-grain: Alfalfa + orchardgrass (3 years) – winter wheat – spring barley. Cropping system 1 (CS1) included three years of an alfalfa-orchardgrass mix to determine if multiple years of legume hay crop alone could supply sufficient N to the following winter wheat crop while providing weed control. Orchardgrass helped alfalfa compete with weeds during the establishment year, but its presence in the alfalfa stand beyond the first year was often low (Fuerst et al. 2009). Winter wheat received no manure fertilizer, and thus relied on N fixed by the alfalfa and any residual or mineralized nutrients. Fertilizer for spring barley following winter wheat consisted of 1 ton per acre of poultry manure, supplying 114 lb per acre of TN.

CS2—Organic 2-year rotation: Winter triticale - winter pea hay. Cropping system 2 (CS2) was designed to include crops that would compete with weeds, in particular a perennial bindweed infestation. Both crops in this rotation were chosen for their weed-control properties. Winter triticale is not widely grown in the Palouse but is a high-biomass and high-yielding grain crop that is competitive with weeds. Poultry manure was applied at a rate of 2 tons per acre (228 lb per acre TN) to the triticale at the time of seeding. Winter pea grown for hay, while not commonly grown, is a nutritious forage that can provide weed suppression when cut several times throughout the growing season.

CS3—*Organic 2-year rotation, low-input GM (green manure): Winter pea GM - winter wheat*. Cropping system 3 (CS3) evaluated GM as the sole source of nutrients for grain production. This system had no manure inputs and no haying. The GM was simply mowed and left on the soil surface.

CS4—*Organic 3-year rotation, high-input grain and annual hay: Spring wheat - winter pea hay - winter wheat*. Cropping system 4 (CS4) was modeled on typical nonorganic rotations in this region, substituting a legume forage (winter pea hay) for a spring legume crop (typically spring peas or garbanzos). Winter and spring wheat crops both received approximately 2 tons per acre of poultry manure (228 lb per acre TN) at seeding time. With the inclusion of winter pea hay, this system received some form of organic N input in each phase of the rotation, with the benefit of weed suppression during the hay production phase.

CS5—*Conventional, no-till 3-year rotation: Spring wheat – spring pea – winter wheat*. Cropping system 5 (CS5) represented a typical nonorganic crop rotation of spring wheat, spring peas, and winter wheat cash crops managed with no-till practices common in the Palouse. This crop rotation was included as a nonorganic comparison in the Boyd ORT trial. However, yields from these plots were below average for conventional crop production in this region. Therefore, the conventional cropping system analysis—including yields, machine operations, fertility, and pesticide inputs—was based on more typical nonorganic inputs and yields reported in University of Idaho (UI) Extension 2018 direct seed budgets for northern Idaho (Painter 2019).

ORT Cropping System Profitability

Yield and Variability

Results from the Boyd ORT cropping systems trials from 2009 to 2013 indicate a wide range of variation in organic crop yield. Winter wheat, winter triticale, and alfalfa yields had the lowest CV values; thus they are more likely to have consistent yields (e.g., less variation) compared to crops with high CV values (Table 3). Yields for both fertilized winter wheat and triticale were higher than ten-year average conventional winter wheat yields in Latah County, Idaho (2002–11). These yields are based on the average of 2–5 years of data, depending on the number of crops in each rotation (Table 3).

Winter wheat. Yields for organic winter wheat were highest in CS4, which received 2 tons of manure, averaging 84 bu per acre (Figure 2, Tables 2 and 3).

Winter wheat yields in CS1, which did not receive any manure but followed three years of alfalfa production, averaged 50 bu per acre. Yields for CS3, which followed a GM crop but did not receive any

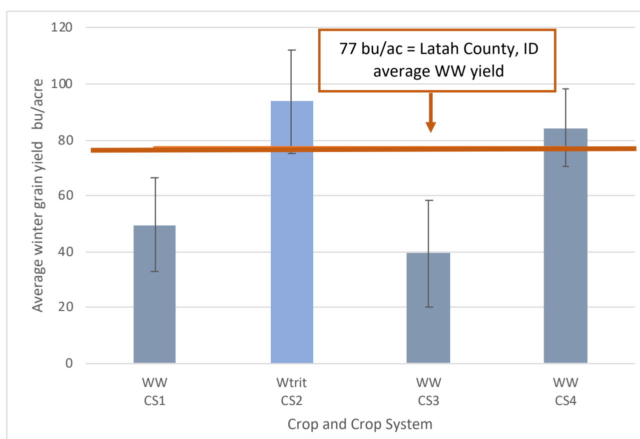

Figure 2. Average winter grain yields from 2009 to 2013, calculated from five plots per cropping system across all years: CS1 (Alfalfa-grain), CS2 (Triticale-hay), CS3 (Low-input, green manure), CS4 (High-input grain), WW = winter wheat, Wtrit = winter triticale. Error bars indicate standard deviation.

Table 3. Summary of yields, coefficients of variance, and revenue per crop year for four ORT cropping systems and one conventional direct-seed cropping system.

Cropping System	Crop	Unit	Yield Per Acre	Coefficient of Variance of Yield (CV) Per Acre	Revenue Per Acre
Alfalfa-Grain	**Organic**				
CS1 Year 1	Alfalfa-Orchardgrass (est.)	ton	0.4	95%	$82
CS1 Year 2	Alfalfa-Orchardgrass (Yr 1)	ton	1.7	35%	$340
CS1 Year 3	Alfalfa-Orchardgrass (Yr 2)	ton	2.3	30%	$460
CS1 Year 4	Winter Wheat	bu	50	34%	$575
CS1 Year 5	Spring Barley	ton	1.1	79%	$346
Triticale-Hay	**Organic**				
CS2 Year 1	Winter Triticale[1]	bu	94	19%	$780
CS2 Year 2	Winter Pea Hay	ton	0.9	57%	$180
Low-input, GM	**Organic**				
CS3 Year 1	Winter Pea Green Manure	--	0.0		$0
CS3 Year 2	Winter Wheat	bu	39	49%	$449
High-Input, Grain	**Organic**				
CS4 Year 1	Hard Red Spring Wheat	bu	33	45%	$446
CS4 Year 2	Winter Pea Hay	ton	1.1	53%	$220
CS4 Year 3	Winter Wheat	bu	84	17%	$966
Conventional	**Conventional**				
CS5 Year 1	Hard Red Spring Wheat[2]	bu	58	--	$348
CS5 Year 2	Spring Pea	lb	1800	--	$198
CS5 Year 3	Winter Wheat	bu	90	--	$495

[1]Winter triticale price/bu assumes 52 lb/bu.

[2]Conventional hard red spring wheat is based on dark northern spring wheat prices.

animal manure applications, averaged 39 bu per acre. Organic winter wheat yields in CS4 exceeded the average conventional winter wheat yield of 77 bu per acre in Latah County, Idaho, from 2002 to 2012 (Figure 2). Yields for the CS4 were also most consistent across trial plots, with the lowest variation in this study (CV = 17%). Relatively high and stable winter wheat yields in this system were the result of adequate soil fertility and weed control.

Organic winter wheat yields were lower than conventional averages in the cropping systems that did not apply manure during the winter wheat production year. Substantial pressure from volunteer alfalfa that was not effectively terminated by shallow tillage before the winter wheat crop was a likely contributor to the lower yields in CS1. Additionally, CS1 received manure fertilizer in just one of every five years, and the application occurred four years prior to the winter wheat, indicating that residual N supplied from alfalfa was not enough to support high WW yields. Similarly, CS3 received no manure and relied solely on residual N from winter pea grown as a GM crop for maintaining soil nutrients, and did not produce competitive yields.

Winter tritcale. Organic winter triticale grown in CS2 was the highest-yielding crop in these trials, averaging 94 bu per acre. This crop also had the second-lowest level of variation (CV = 19%) after fertilized winter wheat. This system was designed for weed control, alternating winter peas as a forage crop (with multiple mowings) with winter triticale, which is very competitive against weeds. High yields for winter triticale were an indicator of its success in competing with weeds and can also be attributed to manure applications of 2 tons per acre.

Spring wheat. Organic hard red spring wheat yields in CS4 averaged 33 bu per acre (CV = 45%), substantially lower than the Latah County average for conventional spring wheat (54 bu per acre, 2002–11). Despite low yields, spring wheat can have some rotational benefits, as it provides an opportunity for mechanical weed control in the early spring (Lorent et al. 2016). The choice of variety can also make a difference in spring wheat yield and weed competitiveness. Earlier research in the Boyd ORT systems trials showed that 'Tara 2002' hard red spring wheat yielded more and had lower weed density than 'Alpowa' soft white wheat (Borrelli et al. 2015).

Spring barley. Organic spring barley was produced on year 5 in CS1, a 5-year system. One ton of manure was applied to this crop. The average yield was 1.1 tons per acre (equivalent to 46 bu per acre) with relatively high variation (CV = 79%). Spring barley yields in 2012 averaged 0.6 tons per acre and were thus considered a crop failure. Yields in 2013 averaged 1.5 tons per acre and were equivalent to conventional Latah County average yields from 2002 to 2011. High variability in yields from year to year suggest that this could be a risky organic crop, yet there is potential for organic barley yields to be comparable to conventional production. Further research is needed to determine the suitability of spring barley for organic rotations in this region.

Alfalfa-Orchardgrass mix. Organic alfalfa-orchardgrass hay yields for the second and third years of production averaged 1.7 and 2.3 tons per ac, respectively, and were comparable to conventional 10-year annual average alfalfa yields for Latah County at 1.9 tons per ac (Table 3). Alfalfa-orchardgrass yields were fairly consistent across plots after the first year, with a CV of 35% in the second year of production and 30% in the third. Yields for the establishment year averaged 0.4 tons per ac (CV = 95%), which is not unexpected for crop establishment, particularly given the challenges of establishment in acidic soils, since alfalfa requires neutral to slightly alkaline soil conditions, particularly during establishment. Competitive, stable yields of alfalfa in years 2 and 3 suggest potential for this crop in mixed perennial-annual crop rotations.

Winter pea hay. Winter pea hay had variable yields across research plots (CV = 57% in CS2 and CV = 53% in CS4), averaging 0.9 tons per ac in CS2 and 1.1 tons per ac for CS4 (Table 3). Winter pea hay provides weed control from multiple cuttings and potentially soil N through biological fixation and breakdown of residual crop biomass (Figure 3).

Grain crops in CS2 and CS4 that followed winter pea also received manure applications, so we cannot separate N contribution from these two sources. However, winter wheat and winter triticale following winter pea hay were the highest-yielding grain crops in the ORT rotations, suggesting that winter pea hay has some agronomic and economic value to ORT crop rotations. While there is no established market for pea hay, local buyers of this product reported that it provided a high-quality forage for their livestock; researchers are exploring its value as a forage crop (Vann et al. 2016).

Figure 3. Winter pea grown for hay.

Crop Price

Organic crop prices used in this analysis are 2018 farmgate prices as reported by the USDA as well as estimates from regional mills (Table 4). Farmgate prices represent net prices to growers after marketing costs have been paid, including transportation. Conventional crop prices are based on University of Idaho Extension annual crop budgets for northern Idaho (Painter 2019). 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 reaching organic crop markets.

Potential Risk of Soil Erosion

STIR values provide an estimate for risk of soil erosion, an important factor to consider alongside profitability for evaluating feasibility and sustainability of these rotations on the Palouse. Based on STIR values calculated from field operations, the conventional no-till system (CS5) has the lowest risk of erosion, followed by Alfalfa-Grain (CS1). The low-input GM (CS3) and high-input grain (CS4) rotations were next, with similar erosion risk, and the triticale-hay (CS2) system had the highest risk (Table 2). While additional assessment of soil erosion is needed, the STIR system suggests higher risk of soil erosion in these ORT rotations than true no-till practices, but they are within the conservation tillage range, defined as having STIR values less than 60 (USDA-NRCS 2008). In general, the STIR values reported here reflect that, including perennial hay and, to a lesser extent, annual hay crops in rotation can reduce soil disturbance and erosion.

Table 4. Prices for organic and conventional crops.

Crop	Unit	Price
Organic soft white winter wheat, food grade	bu	$11.50
Organic hard red spring wheat, food grade	bu	$13.50
Organic barley, food grade	ton	$320.00
Organic alfalfa-orchardgrass	ton	$200.00
Organic winter pea hay	ton	$200.00
Organic winter triticale[1]	bu	$8.30
Conventional soft white wheat	bu	$5.50
Conventional hard red spring wheat[2]	bu	$6.00
Conventional spring pea	lb	$0.11

Sources: Organic grain prices are 2019 estimates provided by a regional grain mill **(Grain Millers, Inc.)** and are within range of national organic price trends. Organic hay prices are estimated from 2018 United States Department of Agriculture-Agricultural Marketing Service Hay reports. Conventional grain prices are regional average prices reported in Painter (2019).

[1]Winter triticale price assumes 52 lb per bu.

[2]Conventional hard red spring wheat is based on dark northern spring wheat prices.

Profitability by Cropping System

Annualized Economic Returns over Total Costs

Under the most optimistic scenario, which assumed organic premiums were received for 100% of production, the alfalfa-grain system (CS1) and the low-input system (CS3) showed negative AER, whereas the triticale-based system (CS2) and the high-input grain system (CS4) exceeded profitability of the conventional comparison, CS5 ($-2/ac; Figure 4).

While returns for the conventional system are negative (though close to breakeven) due to the low price of wheat during this analysis, typically these wheat-based systems are more profitable. While CS2 showed the highest profitability, it should be viewed as an intermediary rotation for the purpose of weed control. Crop rotations longer than two years with a diversity of crops are important for maintaining low weed and pest pressures in organic systems (Liebman and Dyck 1993; Anderson 2010). CS2 demonstrates the potential of winter triticale as an organic crop that can produce high yields under significant weed pressure, especially from the troublesome perennial field bindweed. At $50 per acre, the high-input grain system (CS4) was the second most profitable rotation and, given the longer crop rotation, had the best economic performance coupled with likely the best practices for long-term agronomic stability. While the alfalfa-grain system had negative returns for the entire 5-year rotation (CS1 = -$23/ac), the alfalfa phase had approximately break-even returns in year three. Extending this phase to a fourth year or improving yields during the establishment year might increase the profitability of this rotation. Also, winter wheat yields following alfalfa would likely be higher with better termination of the preceding alfalfa crop. With these improvements, this rotation shows potential for profitability and agronomic sustainability.

In a second scenario, we assumed that only 50% of crop production would be sold with organic price premiums. Mathematically, this is also equivalent to a scenario where 100% of the crop was sold as organic, but premiums were reduced by 50%. Under these conditions, none of the ORT cropping systems had positive returns, although the triticale-based system was closest to breakeven (CS2 = -$10 per ac), with profitability similar to the conventional comparison. The alfalfa-grain system had the second least negative returns over total costs, assuming 50% premium availability, at -$41 per acre (Figure 4).

In a third scenario, we assumed all crop production would be sold at conventional prices in the event that an organic buyer, or market, was inaccessible. Returns for all the organic systems were negative under this assumption (Figure 4). Under current

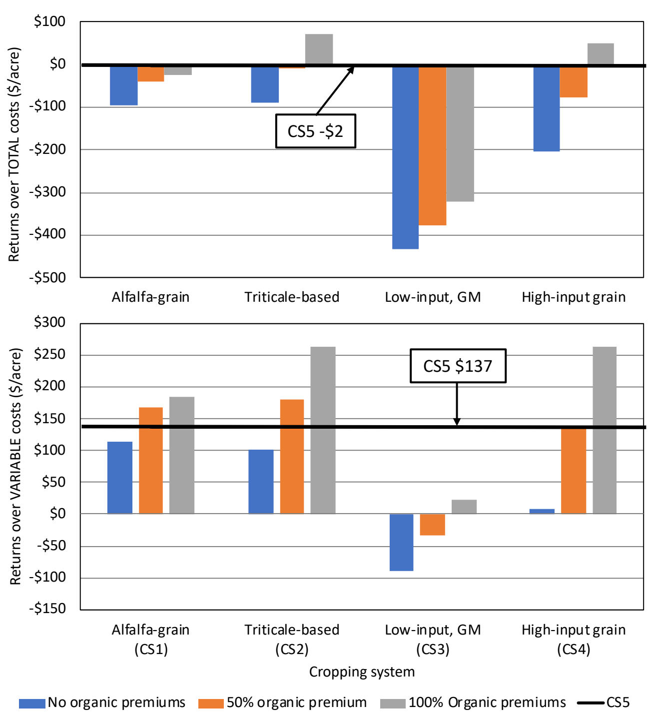

Figure 4. Annualized economic returns over TOTAL cropping system costs of production for four organic reduced-till cropping systems compared to a conventional direct-seed production system (CS-5).

economic and productivity conditions, organic premiums are necessary for these ORT systems to be profitable.

Annualized Economic Returns over Variable Costs

Annualized economic returns over variable costs (RVC) are also termed gross margins. They indicate the short-term profitability of cropping systems, as they exclude fixed costs associated with machinery ownership (e.g., depreciation, interest, taxes, and housing) and land. Looking at these short-term returns[1], all of the ORT cropping systems are profitable when organic premiums are available for 100% of production. The alfalfa-grain (CS1), triticale-hay (CS2), and high-input grain (CS4) systems have higher short-run returns than the conventional comparison at 100% availability of organic premiums. They also have positive short-run returns when no organic premiums are available. With organic premiums for 50% of production, the alfalfa grain- and triticale-based systems exceed the short-run returns of the conventional comparison, and the high-input grain system matches conventional returns (Figure 4).

Operating Costs

Variable cost categories in organic systems differ from those in conventional systems, affecting relative profitability. Machinery costs were generally similar across all crops and rotations, with slightly higher costs for alfalfa production in CS1. Variability in operating costs is primarily a result of differences in fertilizer and seed costs. For instance, winter wheat grown in the alfalfa-grain system had no fertilizer costs, but it also had lower yields and was less profitable overall. In comparison, winter wheat grown in the high-input grain system had higher input costs because of the manure fertilizer, but also higher yield, and was more profitable (Figure 5). Thus, the yield boost in the high-input system more than compensated for the cost of fertilizer, indicating that applying manure fertilizer in this system was a profitable option. Other research in the Palouse found that organic winter wheat grown in rotation

[1]These short-run returns are measured as the annual equivalent annuity of the net present value of returns over variable costs, or what we term annualized economic returns over variable costs.

with three years of alfalfa hay followed by grazed spring peas was profitable without additional fertilizer, though fertilizer would likely be needed in the long run (Wachter et al. 2019). Weighing the availability and cost of organic fertilizer sources against site-specific yield potential can help determine an appropriate ORT crop rotation.

Organic spring wheat grown in the high-input grain system had the highest operating costs. Compared to organic winter wheat, organic spring wheat had higher seed and crop insurance costs (Figure 5). Seeking ways to reduce these input costs would make the high-input grain cropping system (CS4) more profitable. Likewise, the expense for organic winter pea seed is one factor in the lack of profitability for this crop. Finally, the alfalfa hay crop had the lowest operating costs, after the establishment year, indicating that this could be a lower-risk crop to include in rotations. Profitability could be enhanced if production were extended for additional years.

Comparing operating costs of the organic systems to typical no-till conventional systems helps assess their feasibility. Total operating costs per acre for organic wheat that received manure fertilizer (CS4) were slightly higher than the conventional comparison (CS5), and the costs are distributed differently (Figure 5). The conventional system had lower fertilizer and seed costs, but higher expenses for pesticides. The organic high-input grain system had higher fertilizer and seed costs, plus the cost of organic certification and higher crop insurance rates, but no pesticide costs. Operating costs per bushel of winter wheat were also slightly different for the two systems: $2.94 for the organic high-input grain, compared to $2.43 for the conventional no-till system. This difference is a result of slightly higher operating costs and slightly lower yields in the organic system compared to the conventional system. Overall, given the relatively small difference in operating costs between the high-input grain system (CS4) and the

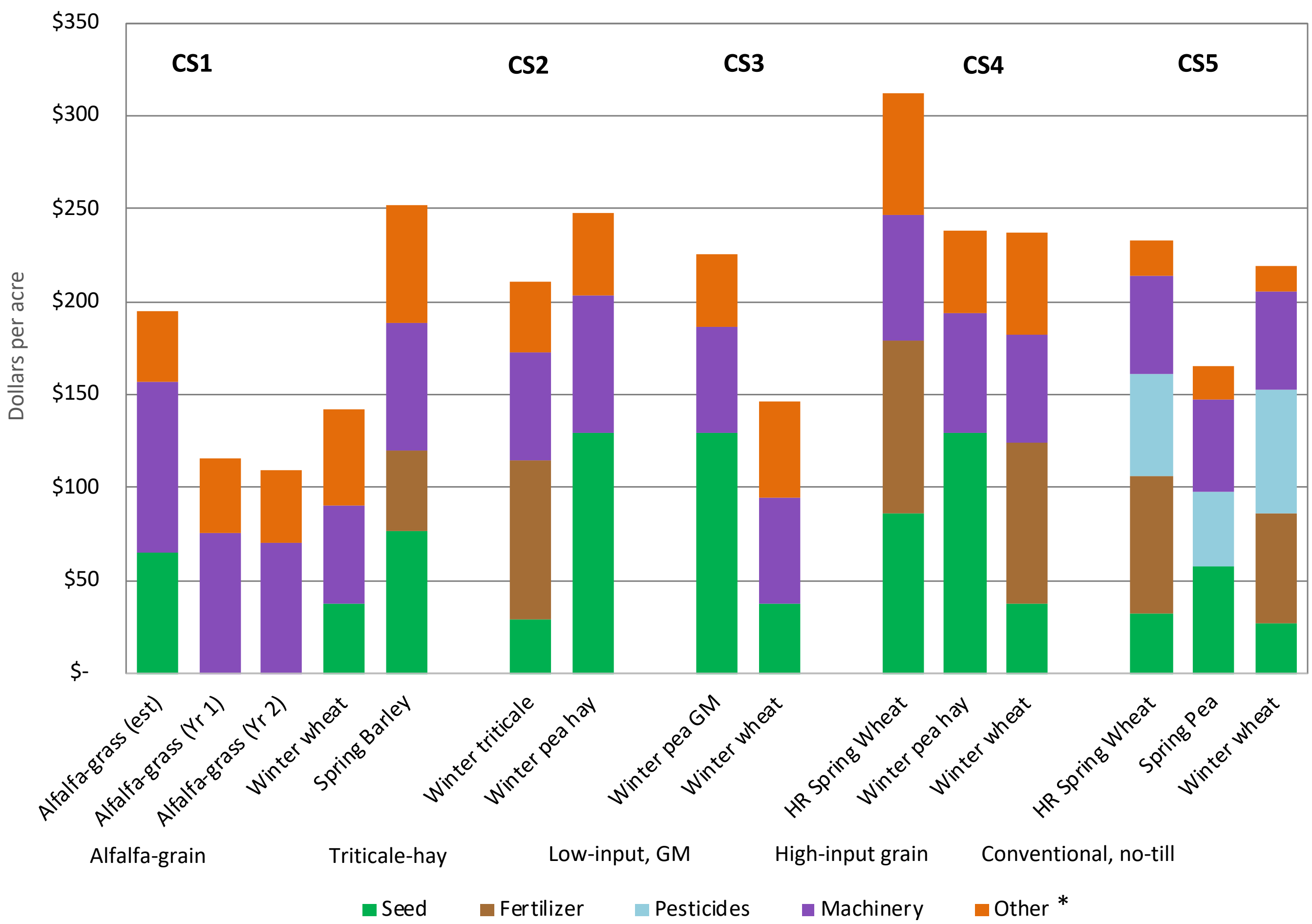

Figure 5. Operating costs by crop in four organic reduced-tillage cropping systems and one conventional, no-till wheat-based system. *"Other" refers to crop insurance, organic certification fees, organic administrative labor, and operating interest.

conventional comparison, **when organic premiums are available, organic wheat production can be more profitable than conventionally grown wheat** within some ORT production systems.

Summary and Recommendations

Based on the Boyd ORT trial, a three-year rotation of spring wheat-winter pea hay-winter wheat (CS4) shows the greatest potential for both economic and agronomic viability. However, characteristics of the other cropping systems in this study may be useful to address specific agronomic challenges in ORT systems. The importance of rotational crops for agronomic benefits like weed control and soil fertility in cropping systems with higher-yielding cash crops is evident from this study. Early and consistent fertility management and weed control, even as early as the three-year transition period rotation, has demonstrated benefits that extend into the certified organic crop production phase (Borrelli et al. 2015). An important distinction of dryland organic systems is that with the restriction of conventional pesticide options, strategies to manage weeds and soil fertility are closely related.

Further experimentation with ORT crop production at the field scale is encouraged, as this study used data from 30 × 50 ft plots. Additionally, a more thorough assessment of soil erosion risk under ORT is needed before fully recommending these practices in the hilly Palouse landscape. Yet, under market scenarios where organic premiums are available, ORT crop rotations that receive fertilizer and include winter grains and legume forages show potential for economic viability in the Palouse. Thus, assessing the price and availability of organic fertilizer sources are important considerations for growers interested in pursuing organic grain production. These rotations use alternative crops that add diversity to the revenue stream, which can reduce economic risk on-farm and help meet the increasing demand for organic grain and forage crops. Finally, this study shows how the integration of reduced-tillage practices with organic grain and forage production can be a sustainable niche market for grain producers in the Palouse with long-term benefits to soil health and profit potential.

Key Findings and Recommendations for Organic Reduced-Tillage (ORT) Cropping Systems in the Palouse

The following are suggestions for developing ORT cropping systems that have a higher potential for economic success in the Palouse dryland region, including lessons from earlier research from the Boyd ORT transition to organic study:

- In the ORT systems presented here, fertilizer and seed costs were the main drivers of operating costs, whereas machinery costs were fairly consistent across rotations. Therefore, access to reasonably priced organic fertilizer is an important factor for determining an appropriate ORT rotation.
- Including spring or winter legume forages in crop rotations in early certified organic production years is important for weed control and soil fertility. Harvest operations (mowing/swathing) that occur throughout the growing season in forage crops control weeds at different times in their life cycle than in grain systems, giving organic growers the opportunity to control weeds that are troublesome in wheat because they mimic wheat life cycles. Legume forages can also add greater amounts of nitrogen (N) to the soil than legumes harvested for grain.
- Crops that establish early and produce high biomass are important for outcompeting weeds and maintaining competitive yields.
- In addition to including legumes in a crop rotation, an organic fertilizer source was necessary to supply N and achieve profitable yields in organic grain crops in this study. However, fertilizer applications are more effective with early, competitive crops. If the crop does not use the available N, the excess soil nutrients can cause an unwanted boost to the weed population.
- High yields and low variability of winter grains like wheat and triticale following an annual legume hay crop like peas suggest that including

these two crop types in rotations successively may improve the profitability of organic grain production due to better soil fertility and weed control.

- While alfalfa hay shows promise as an organic forage crop in rotation with small grains, removal with reduced-tillage implements remains a challenge and can lower grain yields significantly if full removal is not achieved.
- Consistent mechanical weed suppression (mowing and rotary hoeing) throughout the year and within the rotation itself is necessary. Spring crops are typically lower yielding and less profitable, but including these crops in an organic rotation can provide an opportunity to diversify the timing of weed control, allowing for early spring shallow tillage before planting, benefitting weed control in succeeding crops and throughout rotations.
- Crop rotations that are longer than two years are recommended for managing weeds and perhaps controlling other pest pressures in the long term.
- Different cultivars were not evaluated in this study, though cultivar choice can greatly impact crop success. Identifying competitive crop cultivars for organic systems is an area where more research is needed.

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