Accepted for publication 31 January 2011. Published 28 March 2011.

Intensive Crop Rotation Yield and Economic Performance in Minimum Tillage and No Tillage in Northeastern Oregon

John D. Williams and **Dan S. Long,** Columbia Plateau Conservation Research Center, USDA-ARS, Pendleton, OR 97801

Corresponding author: John D. Williams. john.williams@ars.usda.gov

Williams, J. D., and Long, D. S. 2011. Intensive crop rotation yield and economic performance in minimum tillage and no tillage in northeastern Oregon. Online. Crop Management doi:10.1094/CM-2011-0328-01-RS.

Abstract

In the intermediate annual precipitation zone (14 to 18 inches) of northeastern Oregon, there is interest in increasing the intensity of cropping with spring crops. Mechanical tillage remains popular for seedbed preparation and weed control, but contributes to environmental problems and high labor and fuel cost. No-tillage (NT) crop production can reduce on site and off site problems and has lower labor and fuel costs, but soil-borne disease and weed control problems can limit yields. We compared crop yields, production costs, and economic returns of an intensive, four-year crop production rotation under two management systems: (i) minimum tillage (MT) with cultivation by chiseling, sweeping, and rod weeding; and (ii) NT with chemical weed control. The rotation was fallow-winter wheat-dry spring pea-winter wheat in which a spring broadleaf crop is included to aid in the control of winter annual weeds and reduce host pathogen levels of soil-borne cereal diseases. Four year averages of wheat yields in the NT treatment were equal to or greater than those in the MT treatment whereas dry green pea production was roughly equal in each treatment. Crop productivity differed significantly in each phase of the rotation in descending order from winter wheat following fallow [4,578 lb/acre (76 bu/acre)], winter wheat following dry spring pea [3,548 lb/acre (59 bu/acre)], to dry spring pea (1,505 lb/acre). Partial budget analysis shows that NT is substantially less costly than MT in terms of labor and fuel, potentially making NT economically viable for intensive cropping systems in the intermediate precipitation dryland region of northeastern Oregon.

Introduction

A three-year, two-crop rotation of winter wheat-spring cereal-summer fallow is commonly practiced in the intermediate rainfall zone (14 to 18 inches) on the Columbia Plateau of the Pacific Northwest. An exception occurs in northeastern Oregon near the western foothills of the Blue Mountains where rainfall is 15 to 18 inches and winter wheat-summer fallow (WW-F) predominates (17). Producers have relied upon tillage-based WW-F because it has provided them control of weeds, root zone soil water storage, and seed zone moisture following the dry summer months of fallow (11). Increasing the frequency and variety of crops grown in a rotation and adopting no tillage (NT) have been proposed in northeastern Oregon as ways to enhance soil quality and long-term crop productivity (10). In the Great Plains, increasing the variety of crops in rotations resulted in improved annualized grain and crop residue yields over WW-F systems (8). Increased crop frequency and the corresponding reduction of fallow either stabilizes or improves soil organic matter levels (9,13). Improved levels of soil organic matter promote soil aggregation and infiltration (19) resulting in improved soil and water conservation (18). Intensifying production of dryland wheat with a legume rotation improved energy use efficiency in cropping systems on the Canadian Prairies (20).

In southwestern Kansas, Dhuyvetter et al. (3) found that increasing crop intensity from wheat-fallow to wheat-sorghum-fallow increased dollar returns. They compared conventional tillage to NT and found that labor, repair, and petroleum costs declined with NT, but the increased cost of herbicide more than offset these gains. The findings of these same systems in north-central and western Kansas were inconsistent and varied with small changes in yield or production. In Colorado, Peterson and Westfall (8) reported that intensified crop rotations produced higher net returns over WW-F. In other areas of the Pacific Northwest with > 14 inches precipitation, producers experienced in NT and minimum tillage (MT) systems have found these practices profitable (2,4). Intensifying the crop rotation brings added benefits. For example, the addition of a spring crop aids in the control of weeds, particularly winter annuals such as downy brome (*Bromus tectorum*) and the inclusion of broadleaf crops provides additional opportunities for control of rat-tail fescue (*Vulpia myuros* L. C. C. Gmel.) and other grass weeds (1). However, benefits of adopting more intensive cropping systems are negated by the need to insure sufficient soil water for crop production. In addition, adoption of NT for wheat-fallow rotations has been associated with lost productivity attributed to increased weed pressure (1,14).

Some grain growers in northeastern Oregon have already intensified their crop rotations from WW-F, but information is lacking whether it is more economical to control weeds during the fallow period by minimum tillage or by pesticide application. Producers are likely to intensify cropping rotations and adopt NT if there is an economic advantage. The objective of this study was to compare yields and economic returns of more intensive crop production in two management systems: (i) minimum tillage with cultivation by chiseling, sweeping, and rod weeding; and (ii) no tillage with chemical weed control. Productivity (crop yield) and input costs (fertilizer, fuel, herbicide, seed, and time) were evaluated in an alternative, intensive winter wheat-based system in northeastern Oregon.

Experiment with Intensive Wheat Cropping System

A 4-year cropping system study with winter wheat was conducted from 2005 to 2008 at the USDA-ARS Columbia Plateau Conservation Research Center (CPCRC) near Adams, OR (45°43'N, 118°38'W, elevation 1,500 ft). Long-term (1930-2008) annual precipitation is 16 inches with 70% falling during winter and spring (November-April) with 135 to 170 frost-free days (June-September). The growing season for WW is approximately 10 months (October-July) and spring crops can be seeded in early to mid March. The soil is Walla Walla silt loam (coarse-silty, mixed, mesic, superactive Typic Haploxeroll) (5). A meteorological station recorded instantaneous precipitation, and hourly air and soil temperature in each year of the study.

Cropping System and Tillage Treatments

Crops were grown in a four year, three crop system (fallow-winter wheat-spring pea-winter wheat). The experimental design was a split plot with whole plots in randomized complete blocks (6) with four replications. The whole plot treatments were NT and MT, and the split plots were the four phases of the crop rotation. Each whole plot was split into four subplots so that each phase of the cropping system occurred in each year of the experiment. Each phase is termed as follows: phase 1, fallow; phase 2, winter wheat following fallow [WW(f)]; phase 3, dry spring pea (SP); and phase 4, winter wheat following SP [WW(p)]. This arrangement brought to 32 the total number of plots (4 replications × 4 phases × 2 main plots = 32 plots). Individual plots were 12 ft by 150 ft in size and were positioned on ≤ 5% slopes with west and east aspects.

Soil cores were collected to the 48-inch depth in each year before seeding. Soil samples were analyzed in the laboratory for NO_3-N and NH_4-N. Nitrogen fertilizer applications were based on Oregon State University guidelines for winter wheat that use yield goals and soil tests. Nitrogen was applied as dry urea in the NT treatment and as liquid urea (32-0-0) in the MT treatment as necessary to produce WW yields of 75-bu/acre and SP yields of 3000 lbs/acre.

Standing residue in the NT treatment was flailed following harvest, then planted and fertilized fifteen months later in one pass using a Conserva Pak (Indian Head, SK, Canada) medium disturbance hoe drill equipped with stock openers on 12-inch spacing. Openers place starter fertilizer with the seed and additional fertilizer 1 inch below and 1 inch to the side of the seed. In the MT, wheat was seeded using a shank-type, split packer drill on 10-inch centers; peas were seeded using a double disc drill on 7-inch centers. Winter wheat in MT is typically fertilized shortly after primary tillage in the spring in northeastern Oregon. However, producers will fertilize in the fall if they own or use drills capable of fertilizing when they seed, which provides a growth potential advantage to the MT system (15). Standing stubble from WW(f) was flailed following harvest in both NT and MT to get weed seed dropped to the ground for early germination and thus more thorough weed control with subsequent herbicide application or tillage. Winter wheat (cv. Stephens) was seeded at 20 live seeds/ft^2 after F and 21 live seeds/ft^2 after SP. Spring peas (cv. Aria) were seeded at 10 live seeds/ft^2. Target seeding rates were the same in NT and MT.

Weed control in the NT treatment was conducted entirely with herbicides, whereas a combination of mechanical and chemical control was used in the MT treatment (Table 1). Tillage operations in the NT treatment were limited to one pass to sow seed and place fertilizer. In the MT treatment, primary tillage was conducted with a chisel plow, sweep rod, or undercutter. Secondary tillage consisted of cultivation with a sweep-rod (12-inch wide V-sweeps with attached rod-weeder), liquid fertilizer injection, and up to two passes with a rod-weeder. Crops were harvested using a plot combine which spread the chaff and residue back onto the plot.

Table 1. Generalized field operations and inputs for four-year (2005-2008) crop rotation of winter wheat-spring pea-winter wheat-fallow at Adams, OR, using crop year 2005 as an example.

Date[x]	**NT fallow**[y]	**NT WW(f)**	**NT SP**	**NT WW(p)**
Aug			Flail stubble	
Oct '04	Glyphosate	Seed	Glyphosate	Seed
		fertilize		fertilize
				Glyphosate
Nov '04		Propoxycarbazone		
		Mesosulfuron		
Mar '05		Propoxycarbazone	Glyphosate	Mesosulfuron
		Mesosulfuron		Bromoxynil
		Metribuzin		
Apr '05	Glyphosate		Seed	
	Dicamba,		Fertilize	
	2,4-D		Roll	
			Metribuzin	
			Imazethapyr	
			Dinitroaniline	
Jun '05	Glyphosate			
	Bromoxynil			
Jul '05	Glyphosate,			
	2,4-D	Harvest	Harvest	Harvest
	MT fallow	**MT WW(f)**	**MT SP**	**MT WW(p)**
Aug '04			Flail stubble	Primary tillage
Sep '04		Seed		
		fertilize		
Oct '04	Glyphosate			Secondary tillage
				Seed
Mar '05			Primary cultivation	Propoxy-carbazone
			Fertilize	Mesosulfuron
				Metribuzin
Apr '05			Seed	
			roll	
			Metribuzin	
			Imazethapyr	
			Dinitroaniline	
May '05	Primary tillage			
Jun '05	Secondary tillage			
Jul '05	Secondary tillage	Harvest	Harvest	Harvest

[x] General field operations through four years of research. Seed and herbicide application rates varied on year, date, and requirements.

[y] NT = no tillage, MT = minimum tillage, WW(f) = winter-wheat after fall, SP = dry spring peas, and WW(p) = winter-wheat after SP.

Statistical Procedures and Economic Analysis

The data were analyzed using a mixed model with blocks and years as random effects (SAS Institute Inc., Cary, NC). Mean yields were separated using the method of least squares at $P \leq 0.05$. A partial budget analysis was used to compare the costs and benefits of NT and MT, based on plot data from this research. Annual net income for each crop was computed from gross return less variable costs of labor, fuel, and herbicide. Annual net income for each crop was computed from gross return less variable costs of labor, fuel, and herbicide. Annual income was determined per rotational acre by averaging the income from each phase of the rotation (7). Prices received for crops were based on annual market quotes obtained from the USDA-Risk Management Agency for grain at Portland, OR (Table 2). Average published prices for crop years 2005 through 2008 in Oregon were $4.19/bu for WW and $0.08/lb for SP. Fixed costs of depreciation, interest, taxes, housing were not included, nor were variable costs such as crop insurance and equipment repairs. Fertilizer and seed costs were not included, as these variable costs were held constant across treatments. Herbicide costs were based on retail prices at time of purchase and application rates. Fuel costs were based on a set cost of $3/gal for diesel and published fuel consumption rates for a single piece of power equipment under loads appropriate for chisel plowing, herbicide application, and seeding. Labor cost was $10/h based on the amount of time expected to conduct the specified field operation.

Table 2. Crop prices for crop years 2005-2008, Portland, OR (USDA-RMA).

Year	**2005**	**2006**	**2007**	**2008**	**Mean**
Winter wheat ($/bu)	3.50	2.80	3.25	7.20	4.19
Spring peas ($/lb)	0.07	0.07	0.07	0.10	0.08

Crop Yields

Mean annual precipitation was 78%, 127%, 100%, and 89% of the long-term average of 15.4 inches in 2005, 2006, 2007, and 2008 (Table 3). Overall, yield of WW(f) in NT and MT were similar and ranged from 92 to 66 bu/acre while yield of SP ranged from 2027 to 790 lb/acre (Table 3). Differences in yield across years were influenced by precipitation, rotation, and crop management. Most crops exhibited greater yields during 2006 likely because of above average rainfall that occurred in this year. In other years, the variation in yield did not reflect differences in rainfall and temperature. Seasonal precipitation, especially precipitation in May and June has been reported as beneficial to yields of winter wheat (12). With only four years of data, we were unable to find significant ($F \leq 0.05$) and strong correlations between spring or individual months (April, May, June) of precipitation and crop yields (Table 4). However, there were consistently positive slopes and stronger relationships between precipitation and yield in the NT than in MT treatment.

Table 3. Mean crop yields from the winter wheat-spring pea-winter wheat-fallow (WW-SP-WW-F) rotation managed under no till (NT) and minimum tillage (MT), and crop-year precipitation from 2005-2008.

		2005		2006		2007		2008		Overall	
	Previous phase	**WW**[x] (bu)	**SP** (lb)	**WW** (bu)	**SP** (lb)	**WW** (bu)	**SP** (lb)	**WW** (bu)	**SP** (lb)	**WW** (bu)	**SP** (lb)
NT	Fallow	77a[y]	–	82a	–	75a	–	66b	–	75c	–
	SP	87ab	–	93a	–	25b	–	53a	–	64b	–
	WW	–	1634a	–	2027a	–	1595a	–	790a	–	1511a
MT	Fallow	92bc	–	76a	–	69a	–	73c	–	77c	–
	SP	78a	–	66a	–	20b	–	52a	–	54a	–
	WW	–	1452a	–	1988a	–	1042a	–	1638b	–	1530a
Annual precip. (inches)		11.92		19.58		15.46		13.67		**Mean** 15.16	**SD** 3.28
Spring precip. (inches)		5.06		6.47		3.26		2.90		**Mean** 4.42	**SD** 1.66

[x] NT = no tillage, MT = minimum tillage, WW = winter–wheat, SP = dry spring peas.

[y] Values in columns significantly different at $P \leq 0.05$ with different letters.

Table 4. Correlations between precipitation and crop yields during crop years 2005 through 2008.

		NT WW(f)	**NT SP**	**NT WW(p)**	**CT WW(f)**	**CT SP**	**CT WW(p)**
Spring	R²	0.76	0.68	0.75	0.22	0.43	0.49
	F ≤	0.13	0.17	0.14	0.53	0.34	0.33
April	R²	0.86	0.81	0.42	0.02	0.34	0.14
	F ≤	0.07	0.10	0.35	0.85	0.42	0.62
May	R²	0.06	0.05	0.54	1.00	0.05	0.74
	F ≤	0.76	0.79	0.26	0.00	0.79	0.14
June	R²	0.35	0.31	0.06	0.20	0.35	0.06
	F ≤	0.41	0.44	0.75	0.56	0.41	0.96

In 2005, yield of WW(f) was 92 bu/acre in the MT treatment which was significantly greater than yield of WW(p) in the MT treatment and WW(f) in the NT treatment. In 2007, there were no differences in WW yield regardless of tillage treatment and previous phase of the crop rotation. By 2007, however, yield of WW(p) was less than yield of WW(f) in both NT and MT treatments. The significant decline in WW(p) yields following SP could have been the result of depleted soil water by the SP crop, herbicide carry over from SP production, or a combination of both. Pre-emergence herbicide applications in spring crops, followed by relatively dry conditions, creates conditions where herbicides can persist and damage fall planted crops (16). Typically, the plant back interval for WW following the application of a pre-emergence herbicide is 90 days, but considering that precipitation was below average in spring 2007 and 2008 combined with the typically dry summers (Fig. 1), carry over for an additional month appears possible. Yield of SP following wheat did not differ between tillage treatments in 2005, 2006, and 2007, but it was less in the NT treatment versus the MT treatment in 2008. This anomalous yield difference may be explained by colder spring soil temperature in 2008 versus other years. Average soil temperature 14 days after planting was 51°F in 2005, 55°F in 2006, and 59° F in 2007 versus 44°F in 2008. The MT treatment incorporated more crop residue into the soil and thus would have provided a warmer environment for seed germination and crop establishment compared with the NT treatment.

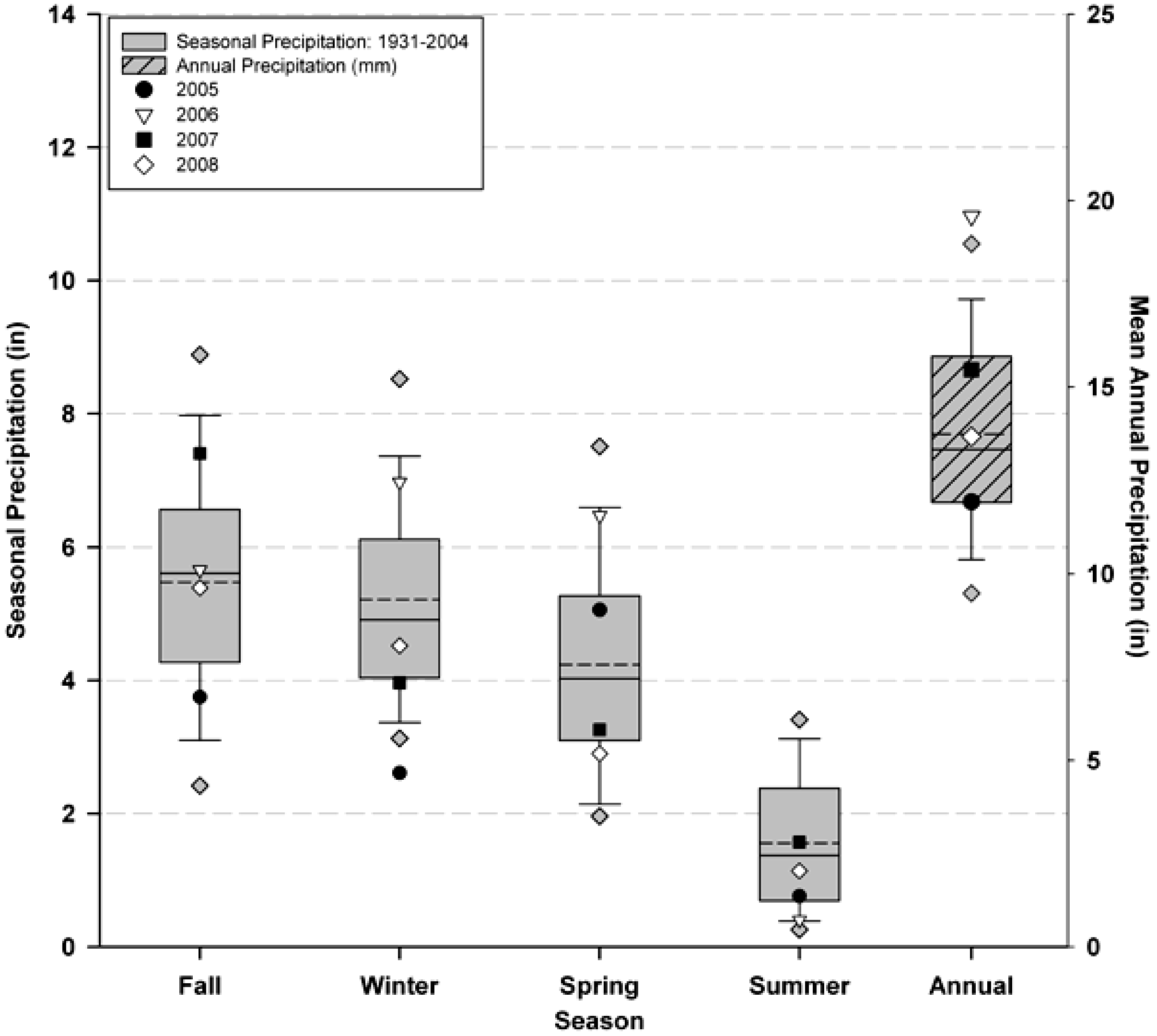

Fig. 1A. Precipitation from crop years 2005 through 2008. The boundary of the box closest to zero indicates the 25th percentile, the solid line within the box marks the median, the dashed line within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentiles. Solid diamonds indicate range of data 5th and 95th percentiles.

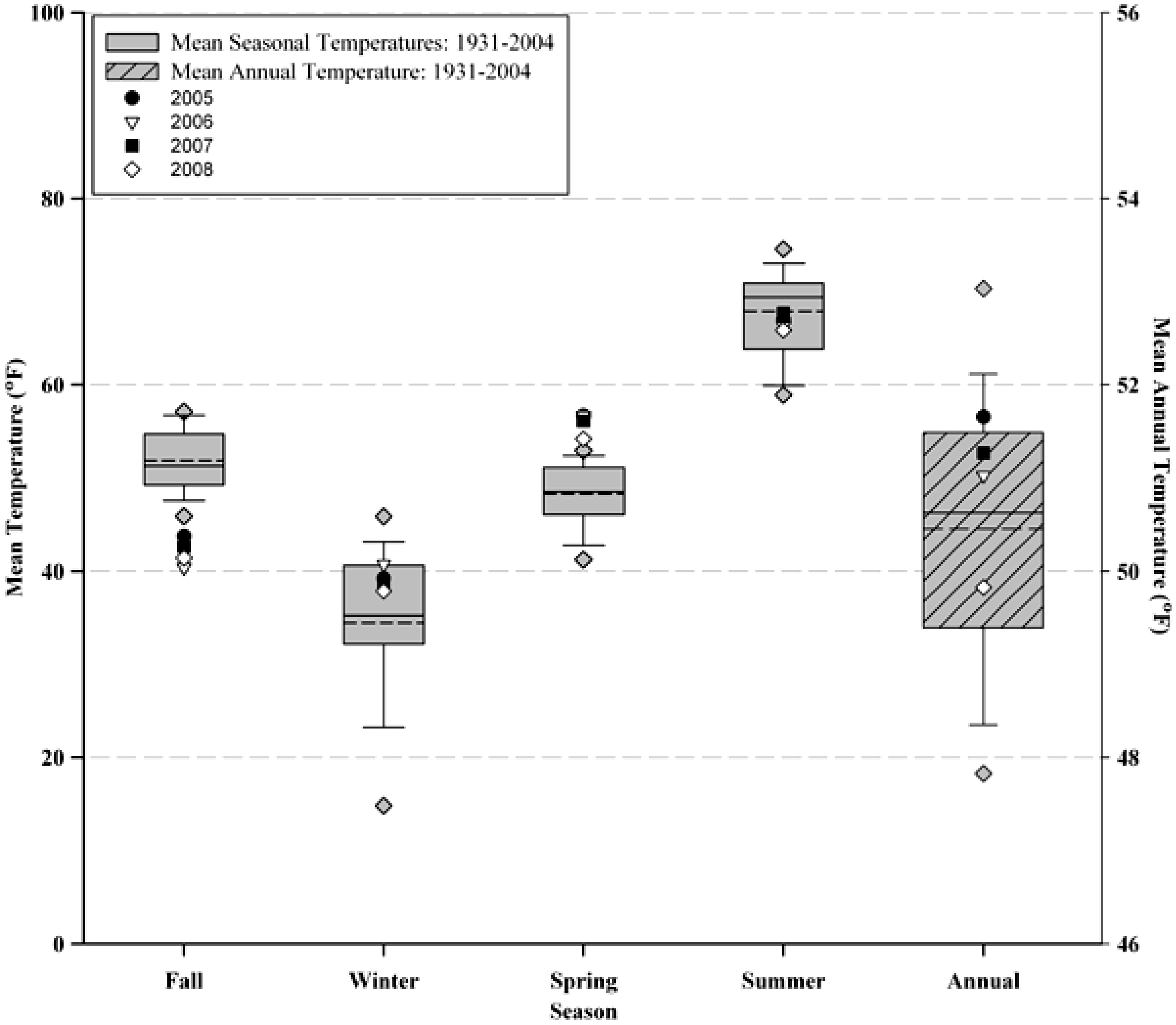

Fig. 1B. Air temperatures from crop years 2005 through 2008. The boundary of the box closest to zero indicates the 25th percentile, the solid line within the box marks the median, the dashed line within the box marks the mean, and the boundary of the box farthest from zero indicates the 75th percentile. Error bars above and below the box indicate the 90th and 10th percentiles. Solid diamonds indicate range of data 5th and 95th percentiles.

Economic Returns and Production Costs

Gross income from NT averaged $8.72/acre more than from MT (Table 5). Labor and fuel costs were consistently lower in the NT whereas herbicide cost was lower in the MT. Over the course of four years, fuel and labor costs averaged $23.79/acre and $42.49/acre ($66.28/acre) more in the MT treatment than in the NT treatment. Conversely, the average cost of herbicide was $40.46/acre less in the MT treatment. The four-year average net benefit realized from reduced costs in NT was $25.82/acre ($66.28-$$40.46 = $25.82), which brought to $34.54/acre the net benefit realized from NT in this four-year rotation. This net benefit represents the increase in profit that may result from the fuel and labor savings of the NT system.

Table 5. Partial budget for four-year rotation under no till (NT) and minimum tillage (MT) near Adams, OR.

Year			**bu/acre**	**$/bu**	**$/acre**
2005	Difference in crop yield (NT−MT)	WW(f)	−15	3.50	−52.94
		WW(p)	9	3.50	30.59
		SP (lb)	182	0.07	12.71
					−9.64
	Difference in cost (NT−MT)	Labor			−3.96
		Fuel			−15.45
		Herbicide			32.91
					13.50
	Net return				−23.14
2006	Difference in crop yield (NT−MT)	WW(f)	6	2.80	16.93
		WW(p)	26	2.80	73.19
		SP (lb)	40	0.07	2.78
					92.90
	Difference in cost (NT−MT)	Labor			−17.28
		Fuel			−44.22
		Herbicide			56.75
					−4.75
	Net return				97.65
2007	Difference in crop yield (NT−MT)	WW(f)	7	3.25	21.92
		WW(p)	6	3.25	19.23
		SP (lb)	553	0.07	38.68
					79.82
	Difference in cost (NT−MT)	Labor			−40.23
		Fuel			−41.67
		Herbicide			14.30
					−67.60
	Net return				147.43
2008		WW(f)	−7	7.20	−51.67
		WW(p)	1	7.20	8.28
		SP (lb)	−848	0.10	−84.82
					−128.20
		Labor			−33.69
		Fuel			−68.61
		Herbicide			57.87
					−44.42
	Net return				−83.78
Avg.	Gross income				8.72
	Operation costs	Labor		−23.79	
		Fuel		−42.49	
		Herbicide		40.46	−25.82
	Net return				34.54

Summary

Variations in the application of cultural practices can number as high as the number of producers using the system. Cultural practices used in this study closely reflect practices observed in northeastern Oregon, and all effort was made to make the results of these experiments representative of what local producers would experience. We conducted a study of a four-year rotation for dryland crop production in the inland Pacific Northwest consisting of winter wheat, spring peas, winter wheat, and fallow. The purpose of the study was to determine the relative productivity of this rotation under minimum tillage and no-tillage management. We found that:

- Crop yields were not significantly different in MT and NT;
- Each phase of the rotation significantly differed in productivity and decreased in order of WW(f) (4,578 lb/acre (76 bu/acre)), WW(p) (3,548 lb/acre (59 bu/acre)), SP (1,505 lb/acre), and fallow;
- A production cost analysis shows NT is substantially less costly in labor and fuel than MT.

Results from this experiment indicate that NT has the potential to be more economically viable than MT for intensive cropping in the intermediate precipitation area of northeastern Oregon. Lower labor and fuel costs provide producers the opportunity to farm increased acreage, extending the depreciation costs of more income and acres, or supplement the cost of equipment by custom rental of equipment. These findings warrant extending the analysis in the future to consider a full enterprise analysis to include the full range of variable costs, fixed costs, and externalities not considered here.

Acknowledgments

We thank Bob Correa, Daryl Haasch, and Dave Robertson for their assistance with field sampling and Amitava Chatterjee for statistical consultation. Mention of manufacturer or trade names does not constitute endorsement by USDA.

Literature Cited

1. Ball, D. A., Frost, S. M., Fandrich, L., Tarasoff, C., and Mallory-Smith, C. 2008. Biological attributes of rattail fescue (*Vulpia myuros*). Weed Sci. 56:26-31.
2. Camara, O. M., Young, D. L., and Hinman, H. R. 1999. Economic case studies of Eastern Washington no-till farmers growing wheat and barley in the 8-13 inch precipitation zone. Farm Business Management Reports, EB1885. Washington State Univ. Coop. Ext., Pulman WA.35 pp.
3. Dhuyvetter, K. C., Thompson, C. R., Norwood, C. A., and Halvorson, A. D. 1996. Economics of dryland cropping systems in the Great Plains: A review. J. Prod. Agr. 9:216-222.
4. Janosky, J. S., Young, D. L., and Schillinger, W. F. 2002. Economics of conservation tillage in a wheat–fallow rotation. Agron. J. 94:527-531.
5. Johnson, D. R., and Makinson, A. J. 1988. Soil survey of Umatilla County area, Oregon. U.S. Government Printing Office, USDA–Soil Conservation Service, Washington D.C.
6. Littell, R. C., Milliken, G. A., Stroup, W. W., Wolfinger, R. D., and Schabenberger, O. 2006. SAS for Mixed Models, 2nd Edn. SAS publishing, SAS Institute Inc., Cary, NC.
7. Nail, E. L., Young, D. L., Hinman, H. R., and Schillinger, W. F. 2005. Economic comparison of no-till annual crop rotations to winter wheat-summer fallow in Adams County, WA, 2001-2004. EB1997E. Washington State Univ. Ext., Pullman, WA.
8. Peterson, G. A., and Westfall, D. G. 2004. Managing precipitation use in sustainable dryland agroecosystems. Ann. Appl. Biol. 144:127-138.
9. Rasmussen, P. E., Albrecht, S. L., and Smiley, R. W. 1998. Soil C and N changes under tillage and cropping systems in semi-arid Pacific Northwest agriculture. Soil Tillage Res. 47:197-205.
10. Rasmussen, P. E., Goulding, K. W. T., Brown, J. R., Grace, P. R., Janzen, H. H., and Korschens, M. 1998. Long-term agroecosystem experiments: Assessing agricultural sustainability and global change. Science 282:893-896.
11. Schillinger, W. F., Papendick, R. I., Guy, S. O., Rasmussen, P. E., and v. Kessel, C. 2003. Dryland cropping in the western United States. Pages 365–393 in: Pacific Northwest Conservation Tillage Handbook. G. A. Peterson, P. W. Unger, W. A. Payne, eds. ASA, CSSA, and SSSA, Madison WI.

12. Schillinger, W. F., Schofstoll, S. E., and Alldredge, J. R. 2008. Available water and wheat grain yield relations in a Mediterranean climate. Field Crops Res. 109:45-49.
13. Sherrod, L. A., Peterson, G. A., Westfall, D. G., and Ahuja, L. R. 2003. Cropping intensity enhances soil organic carbon and nitrogen in a no-till agroecosystem. Soil Sci. Soc. Am. J. 67:1533-1543.
14. Smith, E. G., Peters, T. L., Blackshaw, R. E., Lindwall, C. W., and Larney, F. J. 1996. Economics of reduced tillage in crop–fallow systems. Can. J. Soil Sci. 76:411-416.
15. Veseth, R., McDole, R., Engle, C. F., and Vomocil, J. 1986. Fertilizer band location for cereal root access. PNW Conservation Tillage Handbook Series, Chapter 6 - Fertility, No. 4. Pacific Northwest Solutions to Environmental and Economic Problems (STEEP), reprinted 1989, Univ. of Idaho, Oregon State Univ., Washington State Univ., USDA-ARS, and NRCS, Washington, DC.
16. Volenberg, D., and Boerboom, C. 2007. Herbicide carryover and the drought – roational restrictions for winter wheat. Wis. Crop Manager 14:1-2.
17. Williams, J. D. 2008. Soil erosion from dryland winter wheat-fallow in a long-term residue and nutrient management experiment in north-central Oregon. J. Soil Water Conserv. 63:53-59.
18. Williams, J. D., Gollany, H. T., Siemens, M. C., Wuest, S. B., and Long, D. S. 2009. Comparison of runoff, soil erosion, and winter wheat yields from no-till and inversion tillage production systems in northeastern Oregon. J. Soil Water Conserv. 64:43-52.
19. Wuest, S. B., Caesar-TonThat, T. C., Wright, S. F., and Williams, J. D. 2005. Organic matter addition, N, and residue burning effects on infiltration, biological, and physical properties of an intensively tilled silt-loam soil. Soil Tillage Res. 84:154-167.
20. Zentner, R. P., Lafond, G. P., Derksen, D. A., Nagy, C. N., Wall, D. D., and May, W. E. 2004. Effects of tillage method and crop rotation on non-renewable energy use efficiency for a thin Black Chernozem in the Canadian Prairies. Soil Tillage Res. 77:125-136.