



# Wheat farmers adopt the undercutter fallow method to reduce wind erosion and sustain profitability

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## ABSTRACT

Blowing dust from excessively tilled fallow fields is a major soil loss and air quality concern in the low precipitation (<300 mm annual) wheat (*Triticum aestivum* L.) production region of the Inland Pacific Northwest (PNW) of the United States. A 2-year tillage-based winter wheat-summer fallow (WW-SF) rotation is practiced on >90% of rainfed cropland in the region. Earlier research proved the undercutter method for non-soil inversion primary spring tillage to be environmentally superior and agronomically and economically equivalent to high-soil-disturbance conventional tillage. In this study, we conducted comprehensive surveys of 47 wheat farmers who purchased undercutters through the USDA-Natural Resources Conservation Service (NRCS). Farmers received 50% cost shares on the condition they used the undercutter as prescribed by university scientists on at least 65 ha of land for three consecutive years. Participating farmers were interviewed each year from 2008 to 2010 regarding the agronomic and economic performance of the undercutter versus conventional fallow on their farms. The survey revealed equivalent average WW grain yields and profitability for the two systems from 104 paired comparisons. Survey results also showed that 90% of farmer participants were satisfied with the undercutter system. We conclude the soil-conserving undercutter fallow system provides farmers equal profitability as the conventional-tillage fallow system.

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## 1. Introduction

Research in the Great Plains and Corn Belt of the USA, both summer rainfall regions, has shown economic benefits for direct seeding (no-till) (Dhuyvetter et al., 1996; Horowitz et al., 2010; Uri, 1999; Wiese et al., 1994). Similarly, direct seeding has become increasingly popular in the intermediate (300–450-mm) and high (450–650-mm) average annual precipitation zones of the Inland PNW, where winter precipitation is dominant (Kok et al., 2009; Papendick, 1996; Young et al., 1999).

This study focuses on the low-precipitation (<300 mm annual) zone of east-central Washington and north-central Oregon that encompasses 1.5 million ha of non-irrigated cropland. Essentially all this cropland is in a tillage-based WW-SF rotation. Excessive tillage during SF pulverizes soil clods and buries residue and is the cause of recurrent wind erosion that seriously degrades soil and air quality. Urban locations within this region frequently fail to meet

federal clean air standards for PM<sub>10</sub> emissions during windstorms (Sharratt and Lauer, 2006). The sandy silt loam soils found throughout the WW-SF region have a greater potential to emit PM<sub>10</sub> even though these soils are composed of a smaller percentage of PM<sub>10</sub> compared to the finer-textured silt loam soils found in the intermediate and high precipitation zones of the PNW (Feng et al., 2011).

Long-term cropping systems studies in the low-precipitation zone have examined the feasibility of direct seeding spring-sown wheat, barley (*Hordeum vulgare* L.), and numerous other crops as well as the practice of no-till SF where herbicides are used as a substitute for all tillage operations. Studies have conclusively shown that no alternative crop or cropping system so far tested can compete with tillage-based WW-SF for average and stable profitability (Schillinger and Young, 2004; Schillinger et al., 2007). The absence of significant summer rainfall in the PNW penalizes yields and returns of spring crops and increases their riskiness. Other studies have shown that no-till SF, although ideal for wind erosion control (Sharratt et al., 2010), loses seed-zone water at a faster evaporative rate than does tilled SF during the hot, dry summer (Hammel et al., 1981; Wuest, 2010). This makes it difficult or impossible for farmers to plant WW into carryover soil moisture in late summer with no-till SF whereas adequate seed-zone moisture for planting in late summer can generally be

**Abbreviations:** CRP, Conservation Reserve Program; NRCS, USDA Natural Resources Conservation Service; PNW, Pacific Northwest; WAWG, Washington Association of Wheat Growers; WW-SF, winter wheat-summer fallow.

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achieved with tilled SF. The physics of water loss in tilled versus no-till SF and the grain yield penalties associated with delayed planting of WW are described by Wuest and Schillinger (2011) and Higginbotham et al. (2011).

In review, research conducted in the past two decades indicates that the most realistic method for farmers to mitigate wind erosion and achieve stable and profitable yields in the low-precipitation zone is to practice conservation tillage in a WW-SF rotation. The undercutter system of WW-SF farming was developed for this purpose. The undercutter is a primary tillage implement used in the spring to sever capillary pores and channels to halt liquid flow of water to the soil surface as required for retention of seed-zone water in SF. Undercutter implements are equipped with 80-cm-wide blades with 70 cm spacing between blades on two tiers. Blades have a narrow pitch to allow slicing below the soil surface with minimum soil lifting or disturbance of surface residue (Fig. 1 and Fig. 2). With this system, a tank cart is pulled in front of the undercutter (Fig. 1) to deliver nitrogen and often sulfur fertilizer through a manifold and tubing plumbed beneath both wings of individual undercutter blades. The optimum operating depth for the blades is  $\approx 13$  cm to provide a relatively thick, dry surface soil mulch to retard evaporation during the summer (Wuest, 2010). Conventional primary tillage implements in this region are the tandem disk and field cultivator, both of which mix and stir the surface soil, pulverize soil clods, and bury residue. Following primary spring tillage plus fertilizer injection, farmers use a rodweeder implement equipped with a 1-cm-diameter horizontal square steel rod that rotates opposite the direction of travel at an adjusted depth to uproot weeds with minimum surface disturbance during late spring and summer.

A 6-year field experiment conducted at Lind, WA (242 mm average annual precipitation) showed the undercutter fallow system to be statistically equivalent agronomically and economically to conventional fallow (Schillinger, 2001; Janosky et al., 2002). There were never any differences between undercutter and conventional tillage treatments in precipitation storage efficiency in the soil or in WW grain yield. However, the undercutter method consistently increased surface residue, surface clod mass, and surface roughness compared to conventional tillage (Schillinger, 2001). Wind tunnel tests have shown that the undercutter method reduces soil loss during high winds by up to 70% compared to conventional tillage fallow (Sharratt and Feng, 2009). In addition, due to the recent surge in the cost of diesel fuel and decline in the cost of glyphosate [N-(phosphonomethyl)glycine] herbicide, the undercutter method of farming has potential to provide higher economic returns to farmers compared to conventional tillage (Nail et al., 2007).



**Fig. 1.** A 375 horse power crawler tractor pulls a 3800 L tank cart filled with aqua  $\text{NH}_3\text{-N}$  and a 10-m-wide undercutter implement during primary spring tillage plus N fertilizer injection during the month of April. Photo by W.F. Schillinger.



**Fig. 2.** The undercutter's narrow-pitched and overlapping 80-cm-wide V blades slice beneath the soil at a depth of 13 cm to completely sever capillary channels and halt the upward movement of liquid water to retain seed-zone water in summer fallow for late-summer planting of winter wheat. Most of the winter wheat residue from the previous crop is retained on the surface to control wind erosion. Photo by W.F. Schillinger.

The question is whether these promising experimental results could be duplicated on farmers' fields. To answer this question, the NRCS awarded a \$905,000 Conservation Innovation Grant to the Washington Association of Wheat Growers (WAWG) to 50% cost share the purchase of undercutter implements with farmers. Forty-seven farmers located in 10 counties in Washington and Oregon purchased undercutters through this program. Individual cost-share payments averaged \$15,320, including \$980 for the manifold apparatus and tubing to allow fertilizer application with the undercutter during primary spring tillage. Total payments to farmers equaled \$720,040 with administrative costs absorbing the remainder. As part of the project, participating farmers consented to personal interviews in 2008, 2009, and 2010 about their experience and opinions regarding the undercutter method of farming. The objective of this paper is to report the results of the farmer survey and to discuss the implications for the economic viability of the undercutter system of WW-SF farming in the inland PNW. This study provides a relatively rare multi-year on-farm statistical test of promising field results.

## 2. Materials and methods

### 2.1. Overview

The WAWG/NRCS project provided undercutter implements up to 10 m in width that were fitted to apply aqua or anhydrous  $\text{NH}_3\text{-N}$  at time of primary spring tillage. Undercutter implements determined as suitable for the project were manufactured by Duratech Industries<sup>TM</sup>, Great Plains Manufacturing<sup>TM</sup>, and Orthman Manufacturing<sup>TM</sup>. All 47 participants accepted into the program farmed in the WW-SF region of south-central Washington and north-central Oregon where average annual precipitation ranged from 150 to 300 mm.

All participant farmers agreed to: (i) Leave winter wheat stubble standing and undisturbed from the time of grain harvest in late July–early August until the time of primary spring tillage; (ii) apply glyphosate herbicide at a rate no less than 0.42 kg acid equivalent per hectare in late March or April prior to primary spring tillage to control weeds; (iii) use the undercutter implement for primary spring tillage on at least 65 ha per year for three consecutive years; (iv) apply all nitrogen and sulfur fertilizer needed for the subsequent winter wheat crop with the undercutter during the primary spring tillage operation; (v) operate the undercutter blades at a depth of  $\approx 13$  cm below the soil surface to optimize seed-zone water retention; (vi) rodweed only as required

to control weeds during late spring and summer; (vii) keep accurate records of dates of field operations, rates of fertilizer and herbicides applied, and grain yields; and (viii) participate in twice annual surveys to provide information on their production practices and grain yields as well as their perceptions of the undercutter method for WW-SF farming.

## 2.2. Survey methods

All participants were interviewed in 2008, 2009, and 2010 following spring field operations and again after wheat grain harvest. Responses were recorded on questionnaires prepared by the first author and the WAWG Project Manager. The Project Manager supervised all interviews and was accompanied by the first author on about 20% of the total. Each interview averaged about 80 min. All participant farmers continued to use conventional tillage practices on some of their fields. Data on field operations, input application rates, and grain yields were recorded for undercutter and conventional hectares. The interviewers also collected general information on whole-farm land use, farmers' overall level of satisfaction with the undercutter, and their perceived long-run profit change with the undercutter versus the conventional WW-SF system.

## 2.3. Economic assessment

Survey results revealed that most machine operations and input applications by individual farmers were similar for the undercutter and conventional fallow systems. Consequently, partial budgeting procedures were used as they provide an efficient method for comparing profitability of the two systems by measuring only changes in gross revenue and changes in costs for the undercutter system relative to the conventional system. For example, if the undercutter system decreases gross revenue by \$5/ha, but decreases total costs by \$15/ha, profit for the undercutter system gains \$10/ha over the conventional system. If there was no statistical difference at the 5% probability level in grain yield between the two systems within farmers and years, yields and gross revenues were considered equal. The same statistical criterion applied to cost items.

The profitability comparison includes variable costs for fertilizer, herbicides, seed, labor, and diesel fuel which increase with the number of hectares farmed. Fixed costs; including depreciation, interest, taxes and insurance for machinery and buildings; do not vary over fallow tillage systems because these fixed assets remain the same. Also the land base remains equal under both systems so land costs do not change. Farmers indicated they would keep their conventional primary fallow tillage machinery (i.e., tandem disks and field cultivators) for special conditions, or for part of their land, even after acquiring an undercutter.

Machinery fuel and labor costs also vary with area farmed so are included among variable costs. To estimate fuel consumption and labor cost differences for field operations under the two systems, it was necessary to obtain operating speed (ha/h), and fuel consumption (L/h) for both undercutter and conventional tillage. Fuel costs/ha equal liters of diesel/h divided by cultivated ha/h multiplied by the diesel price/liter. Lubrication and maintenance costs were computed as a small fraction of fuel costs. Labor costs/ha for field operations equal \$/h for wages and benefits divided by ha/h. Labor costs were further inflated by a factor  $F$  showing the ratio of total time to field operating time. For example, if a tractor driver spends 10 h/day in total including fueling the tractor, filling the fertilizer tank cart, adjusting machinery, and making turns versus 8 h/day covering ground in the field,  $F$  equals 1.25. Repair costs/ha, another machinery operation variable cost, are often a function of age and accumulated hours of use. These factors varied

greatly among our sample. We were not successful in eliciting comparable repairs per hectare for the undercutter and conventional implements because the participating farmers had purchased new undercutters and used them for only one to three years. We assumed repair costs were equal across undercutter and conventional tillage implements.

All cost and revenue figures are presented on a rotational hectare basis. For example, a rotational hectare of WW-SF contains 0.5 ha of winter wheat and 0.5 ha of fallow. Crop prices are averages over the experiment era, while input prices are near-term projections.

## 2.4. Statistical methods

Data for WW grain yields, herbicide rates, fertilizer rates, seeding rate, number rodweedings, ha/h for primary spring tillage, and diesel consumption/h for primary tillage were paired by undercutter and conventional tillage systems for the same farms and years. Paired two-tailed  $t$ -tests were employed to determine differences in means. As a descriptive statistic, the percent of pairs that displayed identical practices was computed for number rodweedings and glyphosate rates. We employed Chi-Square to test for independence of fertilizer application method and tillage system, for independence of satisfaction level and survey year, and for independence of long run profit expectations and survey year. All statistical tests were done at the  $P < 0.05$  level of significance.

## 3. Results and discussion

Table 1 displays the average land use reported by participating farmers from 2008 to 2010. Adjustments in leased and owned land caused farm size to change over time. The areas listed undercutter and conventional include both harvested and fallow hectares on which these systems were used. Farmers used the undercutter on an average of 320 ha of "other" land; 392% above their contractual level of 65 ha, and this use grew from 2008 to 2010 (Table 1). Over the three years, participant farmers used the undercutter method on an average of 21% of their cultivated hectares while using conventional tillage on the remaining 79%. This excludes an average of 451 ha non-cropped land enrolled in the Conservation Reserve Program (CRP), 18% of the average farm size of 2323 ha.

Table 2 presents averages and standard deviations of WW grain yields using the undercutter and conventional tillage methods for individual farm sites within the same year as well as averaged over the three years. Matching grain yields by farm site and year is appropriate because agro-climatic factors and management associated with individual farms and years is held constant. For example, if a farmer reported yields in 2008 for only one system, that pair was not included in the sample. The total sample includes 104 complete pairs over the two systems. This sample over a 3-year period and across 10 counties in two states provides for an excellent comparison of the performance between the two fallow systems. The sample size for the undercutter system in 2008 was reduced by delivery delays of undercutters to some farmers during the 2007 fallow year which caused unavailability of yields for a full WW-SF cycle for these farmers. Responses for data decreased

**Table 1**  
Average land use on participating farms by year.

Category	2008	2009	2010
	hectares		
Undercutter: contract	79	82	65
Undercutter: other land	271	311	379
CRP	405	409	538
Conventional WW-SF	1603	1284	1544
Total farm	2358	2086	2526

**Table 2**

Winter wheat grain yields matched by farm and year for conventional and undercutter tillage from 2008 to 2010 as well as the 3-year average.

	Year							
	2008		2009		2010		3-yr avg.	
	Conv.	U.C.	Conv.	U.C.	Conv.	U.C.	Conv.	U.C.
N	14		47		43		104	
Avg. yield (kg/ha)	2311	2211	2022	1996	2970	2956	2452	2419
S.D.	1256	1243	900	1183	934	1028	1055	1209
Paired T P-value	0.404		0.778		0.895		0.619	

slightly in 2010 because that year fell beyond the required reporting period for the project.

Farmers achieved very similar grain yields using the undercutter and conventional systems both in individual years and over all three years (Table 2). The most robust statistical comparison of mean yields is that for all three years which compares the two systems over varying weather conditions. Over 2008–2010 with complete paired data, average yields between undercutter and conventional differed by only 33 kg/ha, or by 1%. The *P* value of 0.619 falls far short of the 0.05 significance level.

Some farmers were initially concerned that less aggressive primary tillage (for example, undercutter versus tandem disk) might increase the number of subsequent required rodweedings. In fact, farmers rodweeded 0.14 fewer times per year on undercutter ground (Table 3). However, the average number of rodweedings was statistically equivalent at the 0.05 significance level. For seventy-four percent of farmer/year pairs the number of rodweedings was identical for the two systems.

Glyphosate is the dominant herbicide for controlling weeds prior to primary spring tillage regardless of tillage system. The survey results showed that farmers used statistically equivalent rates of glyphosate regardless of fallow tillage treatment (Table 3). Participants in the WAWG/NRCS project were contractually required to apply glyphosate at a minimum of 0.42 kg acid equivalent/ha. They applied slightly more than required, averaging 0.45 kg acid equivalent/ha for both their undercutter and conventional fields. As with glyphosate, individual farmers generally applied in-crop broadleaf weed herbicides identically on both undercutter and conventional fields.

Nitrogen fertilizer application rates by individual farmers were statistically equivalent for the two fallow systems, averaging 51, 48, and 55 kg/ha in 2008, 2009, and 2010, respectively. About half the farmers applied sulfur at an average rate of 10 kg/ha tank mixed with their aqua NH<sub>3</sub>-N, and this did not differ significantly between tillage systems. Winter wheat seeding rate averaged 60–67 kg/ha depending on the year and were identical for individual farmers within year over fallow systems.

Having determined that grain yields and input rates were statistically equal for the two fallow tillage systems within farms and years, it is now necessary to assess if machinery operation

costs differed. Project planners initially expected a cost saving with undercutter tillage because application of fertilizer in tandem with the undercutter during primary spring tillage was contractually specified. Indeed, as previously mentioned, participants received an average of \$980 in cost sharing to set up their new undercutter with appropriate manifold and tubing to deliver either aqua or anhydrous NH<sub>3</sub> fertilizer. In practice this expected saving did not materialize because some farmers were unable to inject fertilizer on their undercutter ground due to tractor power limitations, use of custom fertilizer application, and other reasons. Also, most farmers injected fertilizer during primary spring tillage with their conventional-tillage implement. Over the three years, fertilizer was injected during primary spring tillage 76% of the time with the undercutter and 64% of the time with conventional tillage. Independence of fertilizer application method from type of fallow tillage failed significance at the 0.05 level.

Another potential disparity in machinery costs could originate from differences in the cost of primary tillage with the undercutter versus other implements such as the tandem disk or field cultivator on the same farms. A subsample of nine farmers was interviewed about machinery costs in 2009 and 2010, primarily by the first author. These farmers covered an average of 8.65 and 8.09 ha of land per hour and consumed an average of 36.7 and 37.0 L of diesel per hour with their undercutter and conventional primary tillage, respectively. Both the undercutter and conventional primary tillage implements had similar power requirements and sampled farmers generally used the same tractor to pull both implements. Land area tilled and fuel consumption per hour were statistically equivalent.

While not statistically significant, point estimates from the survey showed farmers' subjective satisfaction with the undercutter improved over time. On a scale of 1 = very unsatisfied to 5 = very satisfied, results for satisfaction with the undercutter method averaged 4.1 in 2008, 4.5 in 2009, and 4.7 in 2010. Table 4 shows surveyed farmers' subjective expectations from 2008 to 2010 regarding long-run profit changes using the undercutter method. In all years, 40% or more farmers expected greater profit with the undercutter method. Similarly, a plurality or equal percentage of farmers expected equal profitability with the two systems ranging from 45% in 2008 to 55% in 2010 (Table 4).

The partial budgeting comparison of the two fallow systems is clear and straight forward given the survey results. Statistically equivalent average grain yields on the same farms within years for

**Table 3**

Comparison for number rodweeding operations and glyphosate applications rates matched by farm and year for conventional and undercutter tillage averaged over three years.

	Number of rodweedings		Glyphosate (kg a.e. ha <sup>-1</sup> )	
	Conventional	Undercutter	Conventional	Undercutter
N	117		96	
Average	1.70	1.56	43.13	43.57
Standard deviation	0.91	0.82	13.33	13.25
Percent identical	74		96	
Paired T P-value	0.058		0.059	

**Table 4**Percentage of farmers expecting differing long run profit changes with the undercutter compared to the conventional tillage system by year.<sup>a</sup>

Expected profit change	2008	2009	2010
Higher with undercutter	45	43	40
Same/unsure	45	50	55
Lower with undercutter	10	7	5
Sample size (n)	47	47	33

<sup>a</sup> Farmer expectations were not statistically different over years at *P* < 0.05.

the two systems implied equal economic gross returns. Similarly, statistically equivalent glyphosate, fertilizer, seed, and other input use implied equal costs for these inputs. Furthermore, there were no significant cost differences between systems in fertilizer application or primary spring tillage. Consequently, partial budgeting shows that the undercutter and conventional tillage systems averaged equal profitability. These results obtained from actual farms over three years confirm data of equal profitability based on a 6-year field experiment comparing undercutter and conventional tillage systems reported by Janosky et al. (2002).

Results validate the policy wisdom of the WAWG/NRCS program for evaluating the undercutter on actual farms. As further support for the undercutter system, some equipment dealers have reported selling more undercutters since 2007 outside the cost sharing program than they sold under the program (Harry Schafer, WAWG, personal communication, November 2010).

On the other hand, farmers reported a “learning curve” with the undercutter and variable performance on different soils. Participants complained most frequently about maintaining depth control at speeds greater than 6.5 km/h, blade wear, difficulty operating in heavy residue, shank kickbacks not setting properly, and problems with large soil clods leaving some air voids between the surface and the depth of tillage. Blade wear can be reduced by at least 50% by chrome plating which also permits soil to more easily slide over the undercutter blade, thus reducing drag. Large clods can be readily sized, and air voids eliminated, with a light weight rotary harrow-type implement that attaches directly to the back of the undercutter frame. Many of the farmer participants installed such an attachment on their undercutter.

#### 4. Conclusion

This study provides promising economic results for the environmentally friendly undercutter tillage fallow system. Through paired comparisons of undercutter and conventional tillage systems within the same farms and years during this 3-year study, we conclude the soil-conserving undercutter system provides equal profitability to farmers compared to conventional tillage. This study offers a rare multiyear on-farm statistical confirmation of an innovative conservation tillage technology.

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