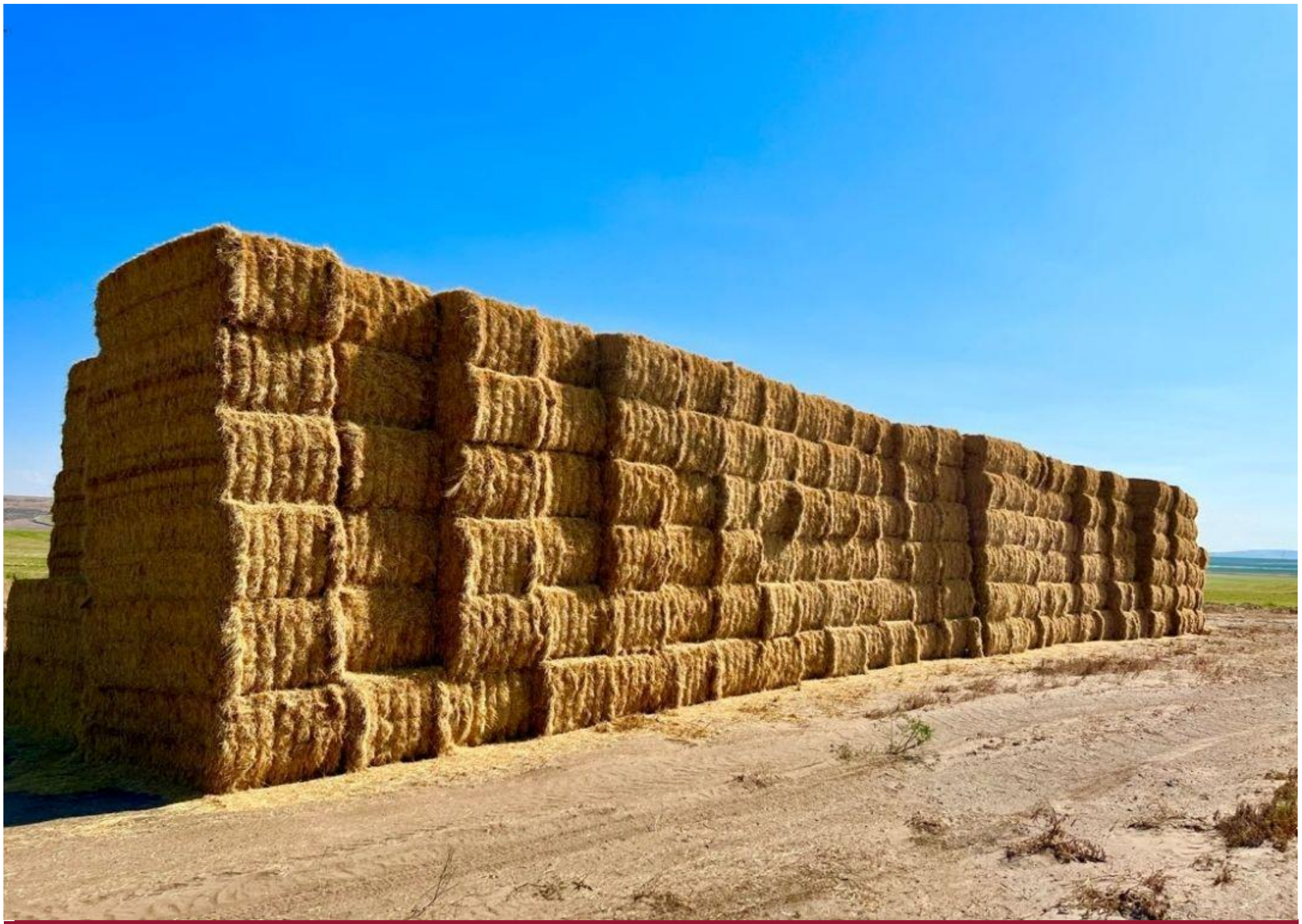

STRAW REMOVAL CALCULATOR GUIDE

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Straw Removal Calculator Guide

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Abstract

Straw removal has become a widespread practice in dryland wheat production in the inland Pacific Northwest (IPNW). While straw harvest may provide short-run economic benefits, there are also potential hidden costs associated with straw harvest. The hidden costs include the depletion of soil organic carbon (SOC) and the removal of nutrients, especially base cations (e.g., K^+, Ca^{++}, and Mg^{++}). This publication serves as a guide for a straw removal calculator designed to assist growers in calculating the hidden costs of straw removal in order to make decisions on whether or not it is appropriate to remove straw under various environments and market conditions.

Overview of Straw Removal

Wheat straw removal has become a widespread practice in dryland wheat production in the inland Pacific Northwest (IPNW). Wheat straw has a variety of end uses, including pulp for paper, forage for livestock, and mushroom growth substrate. From the farm management perspective, straw harvest may supplement the income derived from grain harvest as well as serve as a method for residue management. In recent years, above average wheat yields have led to an increase in straw harvest for the purpose of pulp for paper. While there may be short-term economic and management benefits to straw removal, it is also important to consider the long-term effects of straw removal on soils. There are two primary considerations when it comes to the effect of straw removal on soil health. The first is the depletion of soil organic carbon (SOC) (Saffih-Hdadi and Mary 2008; Tarkalson et al. 2011), and the second is the removal of nutrients, especially base cations.

SOC is perhaps the most important component of soil health, as it directly affects a number of biological, chemical, and physical properties of soil. SOC is both a food source and a habitat for soil microorganisms, and soil microorganisms in turn are critical for soil fertility and nutrient cycling in cropping systems. SOC also improves soil water holding capacity and soil structure, helping to mitigate drought stress and reduce erosion. A minimum aboveground annual input of carbon (MSC) from crop biomass is required to maintain adequate levels of SOC. When using tillage, MSC ranges from 1,964 lb C/acre/year to 3,571 lb C/acre/year, depending on the inclusion of fallow in the rotation, with continuous cropping having a lower MSC value (Huggins et al. 2014; Johnson et al. 2006; Machado 2011; Tarkalson et al. 2009). In no-till continuous cropping systems, MSC is 1,781 lb C/acre/year (Huggins et al. 2014). If SOC levels are to be maintained, straw-associated carbon removal rates should not exceed the MSC value for the given system.

In addition to removing carbon, straw harvesting can result in substantial removal of macro- and micronutrients essential for crop growth (El-Nashaar et al. 2010). In most instances, the removal of N and P in the wheat straw does not result in a meaningful drawdown in those nutrients. In fact, in the short-term, the removal of straw may result in the release of additional N via mineralization from the soil (Brady and Weil 2008). However, in instances where fertilizer prices are above average, the straw N removal may become a concern. Typically, however, the greater concern in the IPNW is the removal of K, Ca, and Mg cations. K, Ca, and Mg are important base cations and play a crucial role in soil pH. Soils which are low in base cations have a greater reserve acidity and a lower pH thereby resulting in higher lime requirements. Many soils in the IPNW are acidifying (McFarland et al. 2015), and the removal of straw may exacerbate the issue.

Calculator Justification

While there are many immediate benefits of straw removal, it is important to quantify the total costs. The purpose of this calculator is to allow producers to better estimate the costs of straw removal. For those who are undecided as to whether or not straw should be removed, this calculator may serve as a helpful decision-making tool.

Often, wheat variety is not considered when estimating straw yield. However, wheat varieties do differ in their harvest index (ratio of grain-to-crop biomass), thus impacting straw yield. This calculator incorporates 54 wheat varieties and their harvest indices to provide producers with a more accurate estimation of straw yield for their particular system. In addition to estimating the biomass available for removal, the calculator determines the nutrients and SOC that would be removed with this biomass if straw is indeed harvested. Nutrient and SOC removal rates must be considered by producers in order to better manage soil organic matter and soil acidity in cropping systems. Finally, the calculator provides a partial budget—including both straw revenue and reduced revenue from additional fertilizer and lime requirements—to give producers an economic basis for straw harvest decision-making.

Calculator Description

General Description

The straw removal calculator uses precipitation or yield data (depending on which is available to the producer) as well as wheat variety to estimate straw yield. The estimated straw yield is then used to estimate the nutrient, base cation, and carbon removal. Along with the prices of straw and fertilizer, straw yield, nutrient removal, and base cation removal rates are used to complete a partial budget for the practice of straw removal on an annual basis.

Estimating Straw Yield Based on Grain Yield and Variety

Grain yield can be estimated based on the prior experience of the calculator user or the available water (defined as soil water at time of planting plus expected April, May, and June rainfall). Alternatively, grain yield is estimated from available water using the following equation (Equation 1).

Equation 1. Yield = 5.81 × available water (in.) − 13.43

The total straw produced is calculated from the grain yield (Equation 2) using the harvest index summarized in Table 1 (sheet labeled “Drop Down 1” in the excel calculator) and the following equation.

Equation 2. Straw produced = (grain yield ÷ harvest index) − grain yield

The harvest index data was collected from the WSU variety trials near Pullman and Reardan, Washington, during the 2021 harvest.

The total straw produced accounts for a 100% harvest of straw. In reality, however, only a fraction of the straw produced by the wheat is removed through baling. The amount of straw removed depends on baling practices and the height at which the straw is cut. The percentage of straw harvested is generally around 45% of the total straw biomass (Lafond et al. 2009; Sokhansanj et al. 2008). However, this number is also adjustable in the calculator as harvest management practices will affect the overall straw removal.

Estimating Nutrient and Base Cation Removal

Nutrient removal rates from straw harvest are calculated using Equation 3.

Equation 3. Nutrient removed (lb/acre) = nutrient concentration (%) × 20 × straw yield (ton/acre)

Wheat straw nutrient concentrations are kept constant regardless of wheat variety due to insufficient data on the nutrient concentrations of the varieties included in this calculator. Future work could serve to better the variety input data in this calculator, as it is known that the concentration of nutrients in wheat straw does vary based on variety (El-Nashaar et al. 2010).

Partial Budget and Economic Cost of Removal

The partial budget estimates net profit or loss based on gross revenue from the straw, the operating costs, and the reduced revenue from the nutrient and base cation removal (Equation 4). The straw revenue is based on the straw yield and the straw price (Equation 5). The operating cost refers to the cost to remove or bale straw and is an input based on the operator’s experience and equipment. The reduced revenue is the sum of all the nutrient and liming costs (Equation 6).

Equation 4. Net profit or loss = straw revenue − operating cost − value of nutrients removed

Equation 5. Straw revenue = straw yield × straw price

Equation 6. Reduced revenue = sum of all nutrient and liming costs ($ N/acre + $ P/acre + $ lime/acre + …)

Calculator Limitations

Every calculator tool is limited by the selection of variables and the accuracy of the data used to develop the calculator. The straw removal calculator attempts to estimate the total costs of straw removal on wheat production operations. While nutrient removal is perhaps the easiest to accurately calculate, base cation and SOC reduction are likely the most important long-term costs associated with straw removal. However, both base cation removal and SOC reduction are complex processes which include biological, physical, and chemical processes and are not fully represented by this calculator’s estimations.

Table 1. Harvest indices of wheat varieties.

Variety	Class*	Harvest Index	Variety	Class	Harvest Index
ARS-Crescent	Club	0.35	**LCS Sonic**	SWW	0.40
Castella	Club	0.38	**Mela CL+**	SWW	0.26
Pritchett	Club	0.36	**TMC M-Idas**	SWW	0.44
Battle AX	HRW	0.38	**TMC M-Press**	SWW	0.42
Canvas	HRW	0.38	**Nixon**	SWW	0.39
Guardian	HRW	0.35	**Norwest Duet**	SWW	0.36
Kairos	HRW	0.37	**Norwest Tandem**	SWW	0.41
Keldin	HRW	0.37	**OR2x2 CL+**	SWW	0.38
LCS Jet	HRW	0.40	**Otto**	SWW	0.40
LCS Rocket	HRW	0.39	**Piranha CL+**	SWW	0.37
Scorpio	HRW	0.35	**PNW Hailey**	SWW	0.36
SY Clearstone CL2	HRW	0.28	**Puma**	SWW	0.35
WB4303	HRW	0.40	**Purl**	SWW	0.38
WB4311	HRW	0.39	**Resilience CL+**	SWW	0.38
WB4394	HRW	0.31	**Sockeye CL+**	SWW	0.37
WB4623 CLP	HRW	0.33	**Stingray CL+**	SWW	0.35
Whistler	HRW	0.36	**SY Command**	SWW	0.40
AP Dynamic	SWW	0.38	**SY Dayton**	SWW	0.41
AP Exceed	SWW	0.38	**UI Magic CL+**	SWW	0.38
AP Iliad	SWW	0.41	**VI Frost**	SWW	0.31
Curiosity CL+	SWW	0.36	**VI Presto CL+**	SWW	0.38
Devote	SWW	0.38	**VI Voodoo CL+**	SWW	0.37
Jasper	SWW	0.35	**WB1529**	SWW	0.41
LCS Artdeco	SWW	0.41	**Xerpha**	SWW	0.36
LCS Blackjack	SWW	0.41	**YSC-215**	SWW	0.37
LCS Drive	SWW	0.40	**Unknown**	SWW	0.38
LCS Hulk	SWW	0.36			
LCS Shine	SWW	0.43			

*Club = winter club wheat; HRW = hard red winter wheat; SWW = soft white winter wheat.

Additionally, when calculating minimum soil carbon levels, this calculator only differentiates cropping systems based on tillage and inclusion of fallow. In reality, crop rotation is also important to consider, as different crops produce differing quantities and qualities of residues. For example, a grass crop dominant system may have a lower minimum soil carbon level necessary to maintain soil health, whereas a system which utilizes a broadleaf every other year will need higher levels of biomass (carbon) retained to maintain soil health over time. See the Further Reading section for more information about the impact of crop rotations on residue production.

How to Use the Calculator

An online version of the straw removal calculator is available at https://smallgrains.wsu.edu/additional-resources/tools-and-calculators/. A printable version of the calculator is included in this publication along with an example of a completed worksheet. Estimated values for nutrient price (Table 2), calcium carbonate equivalents (CCE) for liming products (Table 3), and minimum C production needed to maintain SOC based on tillage practice (Table 4) are provided for users to include in calculations.

1. **Locate information**. Users of the calculator will need to know:
    a. Wheat variety, if known, from Table 1. Otherwise, default is "Unknown."
    b. Grain yield.
    c. Available water, if known (if grain yield is unknown, available water will be used to estimate grain yield).
    d. Straw harvest percentage, if known. Otherwise, default is 45%.
    e. Fertilizer and lime prices (estimated values are given, but users can change based on their experience).
    f. Cropping system descriptor (till or no-till, proportion of fallow).
    g. Straw price (estimated value is given, but users can change based on their experience).
    h. Operating costs to remove straw (fuel, labor, equipment; specific for each user).
2. **Input information from step 1 into the calculator**. Calculator will then calculate straw yield, nutrient removal and value, base cation removal, liming cost to replace base cation, SOC removal, SOC status, and net profit or loss.
3. **Apply information to decision-making**. The calculator provides economic benefit or cost of straw harvest, as well as cost of base cation and SOC removal. One, two, or all three of these factors may be utilized by the calculator user to determine if harvesting straw makes sense in their operation.
4. **Adjust calculator inputs to examine different scenarios**. For example, alter the straw harvest percentage to determine if harvesting less straw is still economical while maintaining higher SOC level, or examine the impact of different wheat varieties on straw yield and net loss or profit.

Table 2. Estimated prices of nutrients.

Nutrient	Nutrient Price ($/lb)
N	1.25
P_2O_5	1.50
K_2O	0.60
S	0.40
Ca	0.20
Mg	0.30
Zn	1.00
B	1.00

Note: Different values may be used in the calculator based on each user's experience and known nutrient prices.

Table 3. Liming materials and their calcium carbonate equivalent values.

Material	Calcium Carbonate Equivalents	Reference
Calcium Carbonate	1.00	Thompson et al. (2016)
Calcitic Limestone	0.97	Thompson et al. (2016)
Dolomitic Limestone	1.05	Thompson et al. (2016)
Sugar Beet Lime	0.77	Thompson et al. (2016)
Liquid Suspended Calcite	0.94	Thompson et al. (2016)
Slags	0.70	Mahler & McDole (1986)
Sludges	0.55	Mahler & McDole (1986)
Wood Ashes	0.40	Mahler & McDole (1986)

Table 4. Soil organic carbon maintenance levels by cropping system.

Cropping System	Minimum Soil Carbon (lb C/acre)	Reference
Till—continuous cropping	1,964	Machado (2011)
Till—1/3 fallow	2,672	Huggins et al. (2014)
Till—1/2 fallow	3,571	Tarkalson et al. (2009) and Johnson et al. (2006)
No-till—continuous cropping	1,781	Huggins et al. (2014)

STRAW CALCULATOR WORKSHEET		
A	**Estimate Grain and Straw Yield from Available Moisture**	
Description	Equation	Output
1. Available water (in.)		
2. Wheat variety (from Table 1)		
3. Harvest index (from Table 1)		
4. Straw harvest percentage	(If unknown, default straw harvest percentage = 45%)	
5. Grain yield (convert bu/acre to lb/acre)	Yield in bu/acre × 60 lb/bu If grain yield unknown: 5.81 × (in. available water) − 13.43 (adapted from Schillinger et al., 2008)	
6. Total straw produced (lb/acre)	(grain yield lb/acre ÷ harvest index) − grain yield lb/acre (Line A5 ÷ Line A3) − Line A5	
7. Straw yield (ton/acre removed)	straw ÷ 2,000 × (straw harvest percentage ÷ 100) Line A6 ÷ 2,000 × (Line A4 ÷ 100)	

B	**Estimate Nutrient Removal**			
Nutrient removed	Nutrient concentration (%)	Nutrient removed (lb/acre): *straw yield (ton/acre) × 20× nutrient concentration* *Line A7 × 20 × (B1, B2, etc.)*	Nutrient price ($/lb) *If unknown, use estimated values from Table 2.*	Nutrient removal cost ($/acre): *nutrient removed × nutrient price*
1. N	0.642			
2. P_2O_5	0.092			
3. S	0.06			
4. Zn	0.01115			
5. B	0.0622			
6. Total Cost of Nutrient Removal ($/acre)				

C	**Estimate Base Cation Removal**		
Base cation removed	Base cation concentration (%)	Base cation removed (lb/acre): *straw yield (ton/acre) × 20 × base cation concentration* *Line A7 × 20 × (C1, C2, or C3)*	CCE of base cations removed
1. K_2O	1.4		K_2O removed × 0.532 =
2. Ca	1.2		Ca removed × 2.5 =

3. Mg	0.87		Mg removed × 4.167 =
4. Total CCE of base cation removal per acre			
5. Liming material (from Table 3)			
6. CCE of liming material (from Table 3)			
7. Liming material price ($/ton)			
8. Base cation removal cost ($/acre): ([total CCE removed ÷ CCE lime material] ÷ 2,000) × price lime material			

D	**Estimate Soil Organic Carbon Removal**
Description	Output
1. Cropping system (from Table 4)	
2. Maintenance SOC (lb/acre) (from Table 4)	
3. C concentration of straw	0.45
4. C removed with straw (lb/acre): *0.45 × 2,000 × straw yield (ton/acre)* *(D3 × 2,000 × A7)*	
5. C not removed (lb/acre): *(total straw produced × C concentration of straw) − C removed with straw* *(A6 × D3) − D4*	
6. SOC status *(if remaining C [D5] > maintenance SOC for cropping system [D2], then SOC is above maintenance level; if remaining C [D5] < maintenance SOC for cropping system [D2], then SOC is below maintenance level)*	

E	**Partial Budget**
1. Straw price ($/ton) *Based on current market price*	
2. Straw revenue ($/acre): *straw price × straw yield* *(E1 × A7)*	
3. Operating costs ($/acre) *(Based on experience or $10/acre default)*	
4. Reduced revenue ($/acre): *nutrient removal cost + base cation removal cost* *(B6 + C8)*	
5. Net (profit/loss) ($/acre): *straw revenue − operating costs − reduced revenue* *(E2 − E3 − E4)*	

STRAW CALCULTOR WORKSHEET—EXAMPLE

A	**Estimate Grain and Straw Yield from Available Moisture**	
Description	Equation	Output
1. Available water (in.)		Unknown
2. Wheat variety (from Table 1)		Stingray CL+
3. Harvest index (from Table 1)		0.352
4. Straw harvest percentage	(If unknown, default straw harvest percentage = 45%)	45%
5. Grain yield (convert bu/acre to lb/acre)	Yield in bu/acre × 60 lb/bu If grain yield unknown: 5.81 × (in. available water) − 13.43	(120 bu/acre) × 60 lb/bu = 7,164 lb/acre
6. Total straw produced	(grain yield lb/acre ÷ harvest index) − grain yield lb/acre (Line A5 ÷ Line A3) − Line A5	(7,164/0.352) – 7,164 = 13,188 lb straw
7. Straw yield (ton/acre removed)	straw ÷ 2,000 × (straw harvest percentage ÷ 100) Line A6 ÷ 2,000 × (Line A4 ÷ 100)	13,188/2,000 × (45/100) = 2.97 ton/acre

B	**Estimate Nutrient Removal**			
Nutrient removed	Nutrient concentration (%)	Nutrient removed (lb/acre): *straw yield (ton/acre) × 20 × nutrient concentration* *Line A7 × 20 × (B1, B2, etc.)*	Nutrient price ($/lb) *If unknown, use estimated values from Table 2.*	Nutrient removal cost ($/acre): *nutrient removed × nutrient price*
1. N	0.642	2.97 × 20 × 0.642 = 38.1	1.25	38.1 × 1.25 = $47.70/acre
2. P_2O_5	0.092	2.97 × 20 × 0.092 = 5.5	1.50	5.5 × 1.50 = $8.20/acre
3. S	0.06	2.97 × 20 × 0.06 = 3.6	0.40	3.6 × 0.40 = $1.40/acre
4. Zn	0.01115	2.97 × 20 × 0.01115 = 0.7	1.00	0.7 × 1.00 = $0.7/acre
5. B	0.0622	2.97 × 20 × 0.0622 = 3.7	1.00	3.7 × 1.00 = $3.70/acre
6. Total Cost of Nutrient Removal ($/acre)				$61.60

C	**Estimate Base Cation Removal**		
Base cation removed	Base cation concentration (%)	Base cation removed (lb/acre): *straw yield (ton/acre) × 20 × base cation concentration* *Line A7 × 20 × (C1, C2, or C3)*	CCE of base cations removed
1. K_2O	1.4	2.97 × 20 × 1.4 = 83.16	K_2O removed × 0.532 = 83.16 × 0.532 = 44.24
2. Ca	1.2	2.97 × 20 × 1.2 = 71.28	Ca removed × 2.5 = 71.28 × 2.5 = 178.2
3. Mg	0.87	2.97 × 20 × 0.87 = 51.68	Mg removed × 4.167 = 51.68 × 4.167 = 215.35
4. Total CCE of base cation removal per acre			438
5. Liming material (from Table 3)		Calcitic limestone	
6. CCE of liming material (from Table 3)		0.97	
7. Liming material price ($/ton)		$40/ton	
8. Base cation removal cost ($/acre): ([total CCE removed ÷ CCE lime material] ÷ 2,000) × price lime material			([438/0.97]/2,000) × 40 + 10 = $19/acre

D	**Estimate Soil Organic Carbon Removal**
Description	Output
1. Cropping system (from Table 4)	Till—continuous cropping
2. Maintenance SOC (lb/acre) (from Table 4)	1,964
3. C concentration of straw	0.45
4. C removed with straw (lb/acre): *0.45 × 2,000 × straw yield (ton/acre)* *(D3 × 2,000 × A7)*	0.45 × 2,000 × 2.97 = 2,673
5. C not removed (lb/acre): *(Total straw produced × C concentration of straw) − C removed with straw* *(A6 × D3) − D4*	(13,188 × 0.45) – 2,673 = 3,262
6. SOC status *(if remaining C [D5] > maintenance SOC for cropping system [D2], then SOC is above maintenance level; if remaining C [D5] < maintenance SOC for cropping system [D2], then SOC is below maintenance level)*	3,262 > 1,964 Above maintenance SOC

E	**Partial Budget**
1. Straw price ($/ton) *Based on current market price*	$60/ton
2. Straw revenue ($/acre): *straw price × straw yield* *(E1 × A7)*	60 × 2.97 = $178.20/acre
3. Operating costs ($/acre) *(Based on experience or $10/acre default)*	$40/acre
4. Reduced revenue ($/acre): *nutrient removal cost + base cation removal cost* *(B6 + C8)*	$61.60 + $19 = $80.60
5. Net (profit/loss) ($/acre): *straw revenue − operating costs − reduced revenue* *(E2 − E3 − E4)*	$178.20 - $40 - $80.60 = $57.60

Further Reading

Podcast

Lyon, D. Sustainable Straw Harvesting with Bill Pan. *Wheat Beat* podcast. Washington State University.

Extension Bulletin

Wheat straw pulping:

Pan, W., P. Carter, and H. Tao. A Wheat Straw Pulping Co-Product Mixed With Lime May Address Soil Acidification in No-till Fields. Washington State University.

Crop residue management and rotational diversification:

McClellan, R.C., D.K. McCool, and R.W. Rickman. 2012. Grain Yield and Biomass Relationship for Crops in the Inland Pacific Northwest United States. *Journal of Soil and Water Conservation* 67: 42–50.

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Existing Calculators

Small Grains Washington State University Extension. n.d. Residue Production Calculator.

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