Impact of Removing Straw from Wheat and Barley Fields: A Literature Review

By David D. Tarkalson, Brad Brown, Hans Kok, and Dave L. Bjorneberg

The sustainability of straw removal from wheat and barley fields from the standpoint of its effects on soil properties and nutrient cycling is a concern. A recent literature review reveals that there is no negative effect of small grain straw removal on soil organic carbon (SOC) content with irrigated conditions. With rainfed conditions, the results could be more variable and depend on site productivity. Large amounts of nutrients are removed when straw is removed, accelerating the rate of nutrient depletion and cost of replacing these nutrients.

Removal of straw from small grain fields has raised concerns about its effects on soil properties and nutrient cycling. Removal of straw for animal bedding and feed, the potential for cellulose-based ethanol production, and impacts on fertilizer and fuel costs are issues of concern.

Straw produced from small grains such as wheat and barley is a source of cellulose for biofuels. The average annual above-ground biomass from all wheat and barley production from 2001 to 2006 in the USA was 70.9 million (M) tons/year (dry weight basis). The total wheat and barley above-ground biomass represented only 25% of the stover produced from corn production in the USA in 2000.

Addition of crop residues to soils is important because they are a major source of organic carbon (C) and nutrients. Organic C positively impacts soil fertility, soil structure, water infiltration, water holding capacity, and bulk density, and it sustains microbial activity. Above-ground crop residues also have many benefits in the field. They act as a physical barrier between the soil and the erosive forces of wind and rain, reduce evaporation, increase water infiltration, and serve as a nutrient source.

This review focuses on two issues: the effects of straw removal on SOC and nutrient depletion. Literature was reviewed to evaluate changes in SOC where small grain straw was either removed or maintained.

Irrigated Conditions

Bordovsky et al. (1999) measured the SOC concentration in the top 0 to 3 in. of soil for continuous irrigated wheat production under both reduced tillage and conventional tillage, and for a wheat-sorghum doublecrop rotation over an 11-year period in Texas. They found that the SOC concentration increased whether residue was removed or incorporated. However, the SOC increased more rapidly when straw was not removed from the field. Average grain yield and above-ground biomass production during this period was 6% higher when the crop residue was not removed for both tillage systems.

Photo by Hans Kok

Effects of removing straw depend on irrigation and other management.

A 3-year furrow-irrigated study conducted by Bahrani et al. (2002) in Iran found a trend for higher SOC in the 0 to 12-in. soil depth when residue was incorporated, measured 3 years after the study was initiated. However, the SOC concentration did not decline during this time, even when residue was removed. The average wheat grain and straw yields were

Table 1. Annual amount of C and straw inputs of wheat needed to maintain soil organic C levels from reported research (adapted from Table 3 of Johnson et al., 2006).

Location	Study duration, years	Tillage	Crop	Irrigation	MSC	MSR
					---- lb/A/yr ----	
Montana	6	V-blade 9-12 cm	Wheat	NI	268	670
Washington	30	Moldboard plow	Wheat-Fallow	NI	3,571	8,928
Nebraska	22	Moldboard plow	Wheat-Fallow	NI	803	2,008
Colorado	84	Moldboard plow	Wheat-Fallow	NI	982	2,455
Washington	23	Moldboard plow	Wheat-Fallow	NI	1,071	2,678
Mexico	5	Moldboard plow	Wheat-Corn	I	1,294	3,235
Sweden	31	Hand tillage	Wheat-Barley	NI	1,339	3,348
Washington	30	Moldboard plow	Wheat	NI	1,785	4,463
Kansas	42	Moldboard plow	Wheat	NI	1,785	4,463
Oregon	45	Moldboard plow	Wheat-Fallow	NI	1,875	4,688

I = irrigated, NI = not irrigated.
MSC = Minimum above-ground annual C inputs needed to maintain SOC levels (minus C from grain). Values are based on above-ground straw residues and do not include below-ground root residues. Data obtained from research.
MSR = Minimum annual above-ground biomass requirement to maintain SOC (minus grain biomass). MSR = MSC/0.4.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium.

significantly greater in plots where the residue was removed or burned than where the residue was incorporated.

Undersander and Reiger (1985) did not measure any difference in SOC between the residue removal treatments during a 14-year study in Texas with furrow irrigation. They found that the average SOC for all treatments increased from 0.76 to 1.24% between 1967 and 1980 at the 0 to 6-in. depth, and remained at 0.67% at the 6 to 12-in. depth. There were no long-term differences in wheat grain yields (average 50 bu/A) and above-ground biomass (average 1.85 tons/A) between residue management treatments.

Curtin and Fraser (2003) showed no difference in total SOC between residue management treatments at the end of a 6-year study with sprinkler irrigation in New Zealand. There were no effects of residue management on straw or grain yield during the study except for one year when incorporating straw reduced grain yield.

Follett et al. (2005) found an increase in SOC in the 0 to 12-in. depth over 5 years with border irrigation for all the straw management treatments receiving N fertilizer. The SOC increased more rapidly when residue was left on the surface with no-tillage than when residue was incorporated with conventional tillage or when the residue was burned. The average wheat yield where residue was burned and tilled was significantly higher (97 bu/A) than when the residue was incorporated into the soil (85 bu/A). The return of residues to the soil consistently increased SOC faster than when crop residue was removed or burned.

Straw management is becoming more important.

The maintenance and increases in SOC observed when residue was removed or burned is noteworthy and likely results from contributions from plant roots and microbial biomass. Studies have reported a range in contributions by below-ground biomass to SOC. Some estimate that between 25 to 50% of the total plant C is present in below-ground biomass.

Precise measurement of below-ground biomass is difficult to measure because of problems associated with sampling and difficulty in estimating C inputs from roots and exudates. Additionally, when crop residue is removed, an unknown and variable portion of the residue remains in the field due to an inability to remove all the biomass.

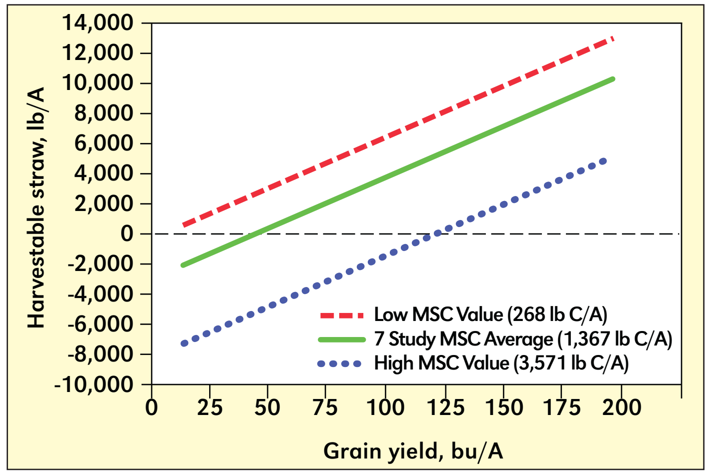

Figure 1. Quantity of annual harvestable wheat straw that maintains SOC (MSC) at a range of grain yields. The solid line represents the average of seven research studies. The dotted and dashed lines represent the upper and lower limits of published information not included in the average line. Specific literature citations used for this study are available from the authors.

Minimum Annual Above-ground Crop Residue Inputs Needed to Maintain SOC

The quantity of C from above-ground wheat residue that needs to be left in the field to maintain SOC levels (MSC) has been previously estimated in rainfed conditions, but this information can be useful for producers making straw-removal decisions from irrigated fields.

Johnson et al. (2006) published the MSC values for wheat production in cropping systems from global literature (**Table 1**). Most of these studies were conducted under rainfed systems in environments where the water supply is variable. With irrigation, plant productivity is generally stabilized at high yield levels, so direct transfer of MSC values between production systems may be only approximate.

We used the MSC values from Johnson et al. (2006) to determine the amount of wheat residue that could be harvested at a range of grain yields while maintaining SOC (**Figure 1**). The middle line represents the average of seven studies that indicated the need for an annual input of 1,367 lb C/A to maintain steady state SOC. Using this line, to maintain SOC, no straw should be removed unless grain yield exceeds 46 bu/A. At a grain yield of 100 bu/A, over 3,500 lb straw/A could be removed without depleting SOC. The dotted and dashed lines indicate the extreme values obtained from the literature. More details on the calculations and methodology are available from the authors.

Table 2. Average nutrient content of wheat and barley straw. Values based on multiple sources.

Crop	N	P_2O_5	K_2O
	----------------	lb/ton	----------------
Wheat	16.2	2.4	20.6
Barley	12.8	1.6	33

Table 3. Economic value of nutrients in wheat and barley straw based on low and high fertilizer prices occurring from 2001 to 2008.

Crop	N	P_2O_5	K_2O	Total
	---------- US$/lb ---------			
Low Prices	0.22	0.25	0.14	
	-------------- US$/ton ---------------			
Wheat	3.56	0.60	2.88	7.05
Barley	2.82	0.40	4.62	7.84
	---------- US$/lb ---------			
High Prices	0.63	0.90	0.47	
	-------------- US$/ton ---------------			
Wheat	10.21	2.16	9.68	22.05
Barley	8.06	1.44	15.51	25.01

Nutrient Removal

Wheat and barley straw contains valuable plant nutrients, so removing this material from the field will speed nutrient depletion and have economic impacts. The average content of N, P, and K in wheat and barley straw based on several published reports is presented in **Table 2**.

Using average nutrient concentrations and a range of fertilizer prices, the nutrient value of straw ranged from US$7.05 to US$22.05/ton for wheat and from US$7.84 to US$25.01/ton for barley straw (**Table 3**).

Straw removal enhances the rate of nutrient depletion compared to systems where only grain is removed. Straw contains less P and N than grain, but a higher proportion of K. The average straw: grain mass nutrient ratio in wheat is 0.47 for N, 0.26 for P, and 4.12 for K. The straw: grain nutrient ratio in barley is 0.49 for N, 0.35 for P, and 5.04 for K. When both grain and straw are removed from fields, soil nutrient depletion (especially K) is more rapid, compared with harvesting only grain.

Nutrient Value in Straw

Estimating the true value of straw must include the need for additional nutrients in subsequent years. For example, fields high in soil K may not immediately require fertilizer inputs to replace the nutrients removed in straw. But in the long-term, nutrients removed in straw will ultimately require replacement to maintain sustainable yields.

It is more difficult to place a value on N removed in straw. When plant residues remain in the field, many recommendations suggest adding extra fertilizer N to overcome temporary N immobilization. The addition of fertilizer can enhance the rate of SOC accumulation. However, if straw is removed, less N may be needed for the following crop until a new organic matter equilibrium is established.

In farming, there are often rental agreements between tenants and landowners. Tenant farmers may be more concerned with short-term economic costs while the landowner may be more concerned with the long-term economic and sustainability impacts. Both parties need to consider the essential role of plant nutrients when making these decisions.

Complex crop rotations on irrigated land that include wheat and barley may be different from those summarized in this paper. For example, in the Pacific Northwest, small grain rotations commonly include alfalfa, corn, potato, or sugar beet. There is very little data that directly relates to these diverse irrigated rotations and the maintenance of SOC.

Photo by Hans Kok

Large amounts of surplus straw are produced with irrigation.

Summary

Consulted data indicate no negative impact on SOC levels by removing small grain straw under irrigated conditions. However, under rainfed conditions, some above-ground residue is generally needed to maintain SOC levels. Under irrigated, high-productivity conditions, it is likely that higher yield levels provide sufficient below-ground biomass to soils to maintain or gradually increase SOC over time. Significant quantities of nutrients are removed from the field when straw is removed. Producers need to include costs of future nutrient replacement to determine the true value of the straw. BC

Dr. Tarkalson (e-mail: david.tarkalson@ars.usda.gov) is Soil Scientist/Systems Agronomist and Dr. Bjorneberg is Agricultural Engineer, USDA-Agricultural Research Service, Kimberly, Idaho. Dr. Brown is Crop Management Specialist, University of Idaho, Parma. Dr. Kok is Conservation Tillage Specialist, University of Washington/University of Idaho, Moscow, Idaho.

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