IRRIGATED SMALL GRAIN RESIDUE MANAGEMENT EFFECTS ON SOIL PROPERTIES

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ABSTRACT

The effects of straw removal from fields under irrigated wheat and barley on soil properties has become a potential concern in Idaho. The demand of straw for animal bedding and feed, and the potential development of cellulosic ethanol production will likely increase in the future. This paper reviews published research assessing the effects of wheat and barley straw removal on soil organic carbon (SOC), and analyzes changes in nutrient cycling within wheat and barley production systems. Six studies compared SOC changes with time in irrigated systems in which wheat was removed or retained. These studies indicate that reductions in SOC due to removal may not be a concern. Soil OC either increased with time or remained constant when residues were removed. It is possible that belowground biomass is supplying C to soils at a rate sufficient to maintain or in some cases, slowly increase SOC with time. A separate research review calculated the minimum aboveground residue required to maintain SOC levels from nine wheat system studies. Eight of the studies were dryland production systems. The grain yields required to produce sufficient above ground biomass to maintain SOC levels ranged from 9 to 122 bu acre^{-1} for wheat and 14 to 185 bu acre^{-1} for barley. Wheat straw contains approximately 15, 3.4, and 33 lbs nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) ton^{-1}, respectively. Barley straw contains approximately 12, 3.9, and 38 lbs N, P_2O_5, and K_2O ton^{-1}, respectively. The calculated total economic value of the N, P_2O_5, and K_2O in one ton of wheat and barley straw is $17.91 and $18.18, respectively, based on average nutrient costs in the Pacific Northwest in 2007. Rotations including wheat and barley in the irrigated agriculture of Idaho and many other states in the Pacific Northwest are much different than what was reported in the reported studies. There is very little reported data that can be directly related the irrigated rotations in Idaho that include wheat or barley. To fully understand the impacts of crop residue removal from soils in Idaho, research projects need to be conducted on crop rotations that include wheat and barley under irrigated conditions in Idaho. Otherwise the best data available for dissemination is from research conducted in different environments and systems.

INTRODUCTION

Several factors have led to concerns regarding changes in residue cycling in some crop production systems. These factors include removal of straw from grain fields for animal bedding and feed, increased costs of fertilizers and fuel, and the potential development of cellulosic-based ethanol production. Crop residue cycling in soils is important because residues are a major supply of nutrients (N, P, and K) and organic carbon (OC) to soils. A plethora of reported research demonstrates the role of SOC in the plant/soil system. Organic C positively impacts soil fertility, soil structure, water infiltration, water holding capacity, reduces compaction, and sustains microbial life in soils (Wilhelm et al., 2007; Tisdale et al., 1993).

Idaho produces 4.5% (8.33 million tons) and 20.8% (3.08 million tons) of the total wheat and barley straw in the U.S., respectively. The demand for straw in Idaho and neighboring states for animal bedding is great and the potential for future cellulosic ethanol production will increase the demand. Understanding the effects of straw removal on SOC and nutrient dynamics in soil systems is important in assessing the sustainability of these systems where residues are removed.

Table 4. Research sources assessing the effects of small grain residue removal strategies on yield, soil physical properties, and soil chemical properties under irrigated conditions.

Source	Site	Soil	Duration	Cropping Systems†	Irrigation	Annual precipitation	Treatments comparisons‡	Selected crop and Soil properties assessed§
			Yr.			mm		
Bordovsky et al. (1999)	Munday, TX	fine sandy loam	11	Cont. W, S-W double crop	furrow	303	CT-RR, CT-RI, RT-RR, RT-RI	SOC, BD, K_s, MA
Bordovsky et al. (1998)	Munday, TX	fine sandy loam	11	Cont. W, S-W double crop	furrow	303	CT-RR, CT-RI, RT-RR, RT-RI	GY, SY¶
Undersander and Reiger (1985)	Etter, TX	silty clay loam	14	Cont. W	furrow	370	RB, RR, RI	GY, SY, SOC, IF
Bahrani et al. (2002)	Kushkak, Iran	clay loam	3	Cont. W	furrow	400	RB, RR, RI	GY, SY, SOC
Curtin and Fraser (2003)	Lincoln, New Zealand	silt loam	6	W-W-B-B-O-O	sprinkler	680	RB, RR, RI	GY, SY, SOC
Follett et al. (2005)	Mexico	clay	5	W-C, W-Bn	border	375	CT-RB, CT-RI, NT-RS	GY, SY, SOC

† W = wheat, S = sorghum, B = barley, O = oat, C = corn, Bn = bean.
‡ CT-RR = conventional tillage-residue removed after harvest, CT-RI = conventional tillage-residue incorporated by tillage, RT-RR = reduced tillage-residue removed after harvest, RT-RI = reduced tillage-residue incorporated by tillage, CT-RB = conventional tillage-residue burned, NT-RS = no tillage-residue left on surface, RR = residue removed, RI = residue incorporated, RB = residue burned, NT-RS = no till-residue left on surface.
§ GY = grain yield, SY = straw yield, SOC = soil organic carbon, BD = bulk density, K_s = hydraulic conductivity, MA = microaggregation, IF = irrigation water infiltration.
¶ All straw yields were calculated using an average harvest index of 0.45 for wheat. Harvest index = grain yield/(grain yield + stover yield).

The objective of this paper is to review published research assessing the effects of wheat and barley residue removal strategies on crop productivity and soil properties in irrigated systems.

METHODS

Results from published literature were reviewed to evaluate changes in SOC associated with management practices where aboveground straw was removed or maintained in fields producing wheat. The N, P_2O_5, and K_2O content and value of wheat and barley straw were calculated from the average values reported by the NRCS Plant Nutrient Content Database (2008).

RESULTS AND DISCUSSION

Table 1 lists the details of the studies that assessed the effects of small grain residue removal soil properties under irrigated conditions.

Soil Organic Carbon

The limited data from research reported in this paper indicate that reductions in SOC due to removal may not be a concern.

Bordovsky et al. (1999) reported the SOC content in the top 3 to 4 in of soil for an irrigated continuous wheat system under both reduced tillage (RT) and conventional tillage (CT), and a wheat-sorghum double crop, but did not conduct statistical comparisons between residue removed (RR) and residue incorporated (RI) treatments for each system involving wheat. The SOC was determined in 1982, 1985, and 1987. Trends indicate that in 1982 the SOC (averaged over the three systems) was similar for the RR and RI treatments (3.6 g kg^{-1}), but in 1985 and 1987 the SOC in RI treatments were 25% and 38% higher than the RR treatment, respectively. However, when comparing the SOC over time, SOC in both the RI and RR treatments tended to increase over time.

In the study conducted by Bahrani et al. (2002), there was a trend for higher SOC in the 0 to 12 in soil depth under the RI treatment than the RR treatment three years after initiation of the study. The SOC did not decline over time regardless of residue management treatment.

Undersander and Reiger (1985) did not show any difference in SOC between residue management treatments (residue burned [RB], RR, and RI) in 1967, 1973, or 1980. The average SOC for all treatments in 1967, 1973, or 1980 was 7.5, 11.4, and 12.2 g kg^{-1} in the 0 to 6 in depth, and 6.6, 7.1, and 6.6 g kg^{-1} in the 6 to 12 in soil depth, respectively. In the 0 to 6 in soil depth, the averaged SOC across all residue management treatments in 1973 and 1980 (11.1 and 12.2 g kg^{-1}, respectively) were significantly higher than the SOC in 1967 (7.5 g kg^{-1}). However, in the 6 to 12 in depth there was no increase in SOC over time.

Curtin and Fraser (2003) showed no difference in total SOC between residue management treatments at the end of their 6-year study. Follett et al. (2005) found an increase in SOC in the 0 to 12 in depth over 5 years for all treatments at an optimum N application rate. The SOC in the WC-RI (wheat corn rotation, residue incorporated) and WC-RB (wheat corn rotation, residue burned) treatments were not different.

The maintenance and increases in SOC over time when residue was removed in these studies are noteworthy and likely result from belowground plant and microbial biomass contributions. The contribution of belowground plant biomass to SOC was not measured in these studies. Understanding the contribution of belowground biomass to SOC is hard to quantify and this can be seen by the variation of values reported in the literature. However, the literature agrees that underground biomass is a significant source of OC to soils. Molina et al. (2001) estimated that 24% of the net C fixed by corn is deposited in the soil from belowground biomass. Kmock et al. (1957) reported that the mass of belowground root biomass from plants is similar to the aboveground residue. Gale and Cambardella (2000) found that roots contribute a greater amount of C to the soil C pool than aboveground residues.

Minimum Aboveground Crop Residue Inputs to Maintain Soil Organic Carbon

Johnson et al (2006) determined the minimum aboveground crop residue requirements to maintain SOC levels (MSC) in soils from several literature reports. Most of these studies were conducted under rain-fed systems in environments where water inputs from precipitation are variable. Under irrigation, above and belowground biomass production is stabilized at a high level as long as other management practices (i.e. nutrient and pest management) are adequate. Because of the potential variation in crop biomass production under a rain-fed environment, changes in SOC and other soil properties under rain-fed environments can be different than under irrigation.

The MSC values from Johnson et al. (2006) for wheat were utilized to determine the amount of residue that could be harvested at various levels of grain yield (Figure 1).

Nutrient Content and Economic Value of Wheat and Barley Straw

Comparisons of the nutrient content per unit mass of straw between values calculated for Idaho using the USDA-NASS and the NRCS Plant Nutrient Database (2008) and an extension article authored by Greg Schwab (Washington State University) are shown in Table 2. The differences in values are due to differences in the average nutrient contents of the straws used in the calculations. The economic values are based on average N, P_2O_5, and K_2O fertilizer costs of \$0.53, \$0.45, and \$0.26 per lb, respectively (average costs for these nutrients in 2007). This gives a nutrient value of \$17.91 and \$18.18 per ton of straw for wheat and barley, respectively (Table 3). It is important that people using the values in Tables 2 and 3 understand that the values are based on estimated production and average nutrient contents over a wide range of wheat and barley varieties. Actual nutrient concentrations in wheat and barley may vary from the calculated values presented in this review. However, the table values are a good tool for an initial assessment of potential nutrient removal.

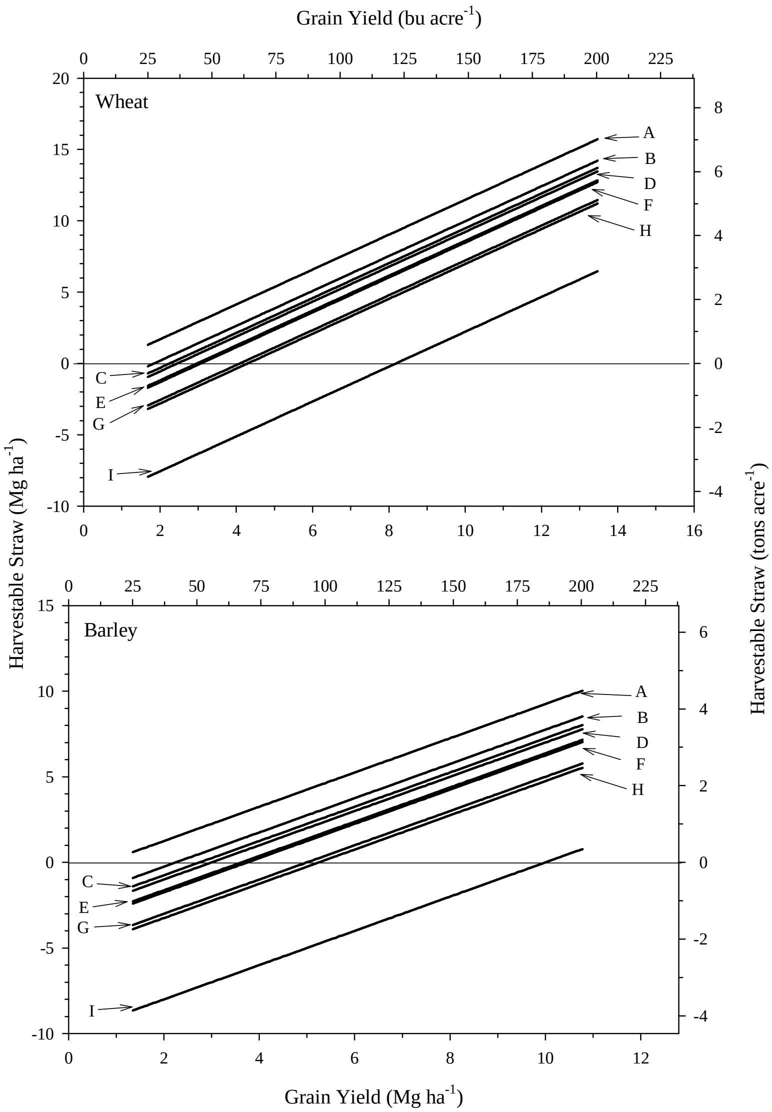

Figure 1. Estimated quantities of wheat and barley residue that could be harvested while maintaining soil organic carbon level as a function of grain yield from various published MSC values [A = Black (1973); B and C = Follett et al. (1997); D = Horner et al. (1960), Rasmussen et al. (1980); E = Follett et al. (2005); F = Paustian et al. (1992); G = Horner et al. (1960), Paustin et al. (1997), Hobbs and Brown (1965), Rasmussen et al. (1980); H = Horner et al. (1960), Rasmussen et al. (1980); I = Horner et al. (1960), Paustin et al. 1997)]. Lines represent linear regression relationships between grain yield and harvestable straw. Data points were not shown in order to make the graphs less cluttered. (Graph based on method used by Wilhelm et al., 2007).

Nutrient mass and economic value estimates from Tables 2 and 3 are based on 100% straw removal. When straw is baled and removed, lower amounts of straw and nutrients will be exported from the field. To determine the actual amount and economic value of the nutrients exported, the total estimates from Tables 2 and 3 will need to be multiplied by the fraction of straw being removed.

Table 2. Average nutrient content in straw per unit mass of straw calculated from data from the NRCS Plant Nutrient Content Database and data reported in a Washington State University Extension publication authored by Greg Schwab.

Crop	Source	lb N/ton	lb P_2O_5/ton	lb K_2O/ton
Wheat	NRCS Plant Nutrient Content Database	15	3.4	33
	Schwab (Washington State University Extension)	12	3.7	20
Barley	NRCS Plant Nutrient Content Database	12	3.9	38
	Schwab (Washington State University Extension)	15	4.1	41

Table 3. Average value of nutrients in wheat and barley straw†.

Crop	N	P_2O_5	K_2O	Total‡
	------$ Mg^{-1} ($ ton^{-1})§------			
Wheat	8.66 (7.86)	1.68 (1.53)	9.40 (8.53)	19.75 (17.91)
Barley	7.11 (6.45)	1.93 (1.75)	10.99 (9.97)	20.04 (18.18)

† Straw production was calculated from grain data using equation (1), grain test weights of 60 and 48 lbs bu^{-1} and harvest index values of 0.45 and 0.5 for wheat and barley, respectively. Approximately one ton of straw per 27.3 and 41.7 bu of grain for wheat and barley, respectively.
‡ Based on plant nutrient content values from the NRCS Plant Nutrient Content Database (http://www.nrcs.usda.gov/TECHNICAL/ECS/nutrient/tbb1.html). Values from Table 9 were used in the calculations.
§ Nutrient values of $0.53, 0.45, and 0.26 were used per lb of N, P_2O_5, and K_2O. Values were based on data from the USDA-NASS and represented average fertilizer prices in the Northwest U.S. in 2007. (http://www.nass.usda.gov/QuickStats/).

Conclusions

The limited data from research evaluated in this paper assessing residue management of wheat and other small grains under irrigated conditions indicate that reductions in SOC due to removal may not be a concern. However, there is very little reported data that directly relates to irrigated rotations in Idaho that include wheat or barley. To fully understand the impacts of crop residues on soils in Idaho, research projects need to be conducted that account for the major crop rotations that include wheat and barley under irrigated conditions. Otherwise, the best data available for dissemination is from research conducted in different environments and systems.

Nutrients are removed from the soil/plant system when straw is harvested. Producers will need to determine the cost of nutrients removed from their systems to determine the value of the straw.

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