IRRIGATED SMALL GRAIN RESIDUE MANAGEMENT EFFECTS ON SOIL PROPERTIES AND NUTRIENT CYCLING

David Tarkalson, Brad Brown, Hans Kok and Dave Bjorneberg
USDA-ARS Agronomist/Soil Scientist, Kimberly, ID; University of Idaho Extension Soil and Crop Management Specialist, Parma, ID; Washington State University Conservation Tillage Extension Specialist, Moscow, ID; USDA-ARS Agricultural Engineer, Kimberly, ID.

ABSTRACT

The effects of straw removal from irrigated wheat and barley fields on soil properties and nutrient cycling is a concern due to its potential impact on the sustainability of agricultural production. The demand for animal bedding and the potential development of cellulosic ethanol production will likely increase straw demand in the future. Previous reviews addressing changes in soil properties when crop residues are removed focused primarily on rain-fed systems. 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 irrigated wheat and barley production systems. Six studies compared SOC changes with time in irrigated systems in which wheat straw was either removed or retained. These studies indicated that SOC 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 (MCS) from nine wheat system studies. Calculations of the MCS values were from rain-fed systems and are likely the best information available presently, for use in evaluating residue removal effects in irrigated systems. However, long-term studies are needed to obtain reliable data for diverse irrigated systems. Nutrients removed from the soil/plant system with straw can be worth $7 to $20 per Mg of straw removed. Producers will need to determine the cost of the nutrient removal from their systems to determine the value of the straw.

INTRODUCTION

Removal of straw from grain production fields where residue was historically incorporated with tillage has many parties concerned about the effects on soil properties and nutrient cycling. Several changes and potential changes in straw management have led to these concerns including 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.

Due to potential increases in biofuel demand, the ethanol industry will likely cause more residue removal from crop land. The immediate and long-term effects of removing aboveground crop residues from fields on crop productivity and sustainability are a concern. A series of policies have pushed for the increased production of biofuels, including the Biomass Research and Development Act (2000), the Energy Policy Act (2006), the Energy Independence and Security Act (2007, which mandated a production of 136.2 billion gallons of biofuels by 2022) and the 2002 and 2008 Farm Bill (Biomass Research and Development Initiative, 2008).

Current ethanol production in the U.S. is primarily from corn grain. However, current research is exploring methods of using cellulosic based products to produce ethanol. Cellulose biomass sources include agricultural crop residues, wood crops, industrial and municipal wastes, lumber wastes, and animal manures (Perlack et al. 2005). Straw produced from small grains such as wheat and barley can also be a source of cellulose for ethanol production (Nelson, 2002; Johnson et al., 2007). Ethanol derived from cellulose is currently the leading candidate of alternative fuels to replace a large portion of the U.S. petroleum-derived fuels (USDOE-NREL, 2006). Total wheat and barley aboveground biomass represents 25.3% of the stover produced from corn production in the U.S. in 2000 (USDA-NASS, 2008; Wilhelm et al., 2004). However, under conservation tillage practices, maintaining a base amount of residue will be required to help prevent excessive soil erosion (Nelson, 2002).

The management of crop residues in cropping systems is becoming an important issue in many areas of the U.S. 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 carbon positively impacts soil fertility, soil structure, infiltration, water holding capacity, soil density, and sustains microbial life in soils (Johnson et al., 2006; Tisdale et al., 1993). Aboveground crop residues have many benefits in the field. They can act as a physical barrier between the soil and the erosive forces of wind and water, reduce evaporation, increase infiltration, and serve as a nutrient source for future plants.

This paper will focus on two issues that tend to be a concern to producers when assessing straw removal from areas that historically have recycled straw in their production systems. These issues include the effects of straw removal on soil properties, and the amount and cost of nutrients removed with the straw. To address these issues in this paper we shall: 1) review published research assessing the effects of wheat and barley residue removal strategies on SOC in irrigated systems, 2) evaluate existing literature assessing the minimum carbon requirements to maintain soil organic carbon levels in rainfed and irrigated conditions, and 3) evaluate existing literature that reports concentrations of selected nutrients in wheat and barley straw to evaluate the economic considerations when residues are removed.

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 small grains. The N, P, and K content and value of wheat and barley straw were obtained from published research and NRCS Plant Nutrient Content Database (available at: http://www.nrcs.usda.gov/technical/ecs/nutrient/tbb1.html.)

RESULTS AND DISCUSSION

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

Soil Organic Carbon

Bordovsky et al. (1999) reported the SOC content in the top 7.5 cm of soil for a continuous wheat system under both reduced tillage (RT) and conventional tillage (CT), and the wheat-sorghum double crop.

Table 2. 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 (DC)	furrow	303	RR-CT, RI-CT, RR-RT, RS-RT	GY, SY[¶], SOC, BD, K_s, MA
Undersander and Reiger (1985)	Etter, TX	silty clay loam	14	Cont. W	furrow	370	RR-CT, RI-CT, RB-CT	GY, SY, SOC, IF
Bahrani et al. (2002)	Kushkak, Iran	clay loam	3	Cont. W	furrow	400	RR-CT, RI-CT, RB-CT	GY, SY, SOC
Curtin and Fraser (2003)	Lincoln, New Zealand	silt loam	6	W-W-B-B-O-O	sprinkler	680	RR-CT, RI-CT, RB-CT	GY, SY, SOC
Follett et al. (2005)	Mexico	clay	5	W-C	border	375	RB-CT, RI-CT, RS-NT	GY, SY, SOC

[†] Cont. = continuous, W = wheat, S = sorghum, B = barley, O = oat, C = corn.

[‡] RR-CT = residue removed after harvest followed by conventional tillage, RI-CT = residue incorporated with conventional tillage, RR-RT = residue removed after harvest-reduced tillage, RS-RT = residue left on surface-reduced tillage, RB-CT = residue burned followed by conventional tillage, RS-NT = residue left on surface-no tillage.

[§] GY = grain yield, SY = straw yield, SOC = soil organic carbon, BD = bulk density, Ks = hydraulic conductivity, MA = microaggregation, IF = irrigation water infiltration.

[¶] All SY's were calculated using an average harvest index of 0.45 for wheat. Harvest index = grain yield/(grain yield + stover yield).

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 residue removed (RR) and residue incorporated (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.

Undersander and Reiger (1985) found no difference in SOC between residue management treatments (RB, RR, RI) in 1967, 1973, or 1980. The average SOC for all treatments in 1967, 1973, or 1980 was 7.6, 11.3, and 12.4 g kg^{-1} in the 0 to 15 cm depth, and 6.7, 7.2, and 6.7 g kg^{-1} in the 15 to 30 cm soil depth, respectively. In the 0 to 15 cm soil depth, the average SOC content over all residue management treatments in 1973 and 1980 (11.3 and 12.4 g kg^{-1}, respectively) were significantly higher than the SOC contents in 1967 (7.6 g kg^{-1}). However, in the 15 to 30 cm depth, there was no increase in SOC over time.

In the study conducted by Bahrani et al. (2002), there was a trend for higher SOC in the 0 to 30 cm soil depth under the RI treatment three years after initiation of the study. The SOC concentration did not decline significant during this three-year study, regardless of residue management treatment.

Curtin and Fraser (2003) showed no difference in total SOC in the 0 to 15 cm depth between residue management treatments at the end of the six-year study (mean = 31.2 g kg^{-1}). Follett et al. (2005) found an increase in SOC in the 0-30 cm depth over five years for all treatments. The change in SOC for the RS-NT (residue left on the surface-no tillage) treatment (+17.5 Mg ha^{-1}), of a wheat-corn rotation compared to the initial level, was higher than the RI-CT (residue incorporated with conventional tillage) (+6.6 Mg ha^{-1}), and RB-CT (residue burned followed by conventional tillage) (+4.9 Mg ha^{-1}), treatments which were not different.

The maintenance and increases in SOC with time when residue was removed or burned in these studies is noteworthy and likely result from belowground plant and microbial biomass contributions. These findings are similar to those reported by Campbell et al. (1991), who hypothesized that C from roots contribute more to maintenance of SOC than aboveground wheat residue. The contribution of belowground plant biomass to SOC was not accounted for in these studies (Table 1). As previously mentioned, understanding the contribution of belowground biomass to SOC is hard to quantify. This can be seen by the variation of values reported in the literature. Changes in SOC may also be influenced by the fact that when residue is removed from fields, a portion of the aboveground residue remains due to an inability to remove all residues.

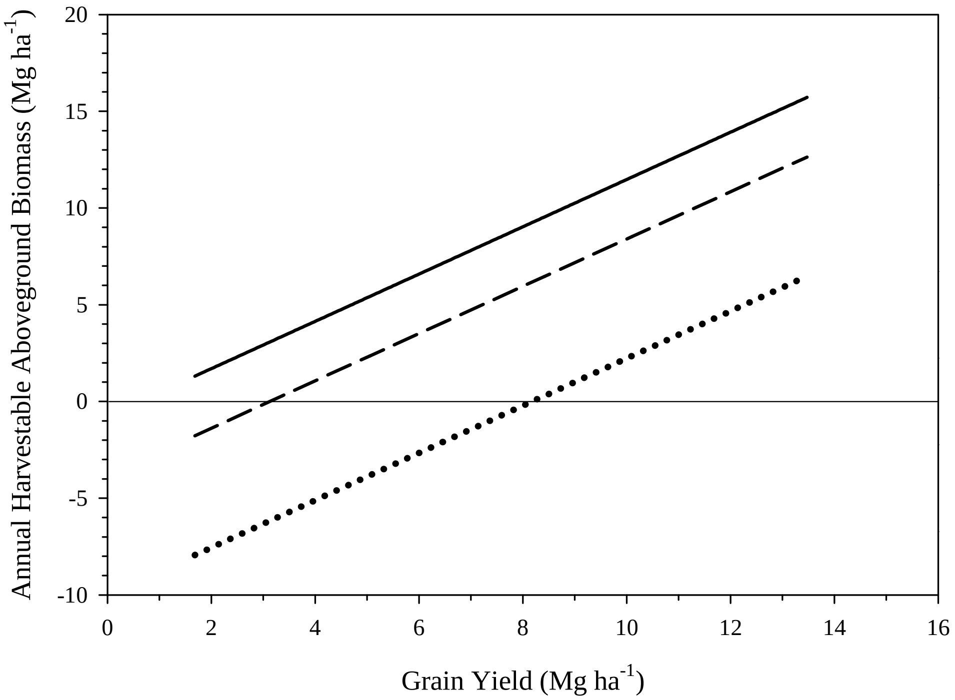

Figure 1. Estimated quantities of annual harvestable wheat and barley above ground biomass (minus grain) based on MSC values (Table 6), at a range of grain yields. Lines represent linear regression relationships between grain yield and harvestable straw. (Graph based on method used by Wilhelm et al., 2007). Dashed line was derived from average MCS values due to a close range of the values, and solid and dotted lines represent low and high MCS values (respectively) of the studies reported in by Johnson et al. (2006).

Minimum Aboveground Crop Residue Inputs to Maintain Soil Organic Carbon

No studies have determined the minimum annual aboveground crop carbon requirements to maintain SOC levels (MSC) with wheat in cropping systems under irrigated conditions. However, several studies have determined MCS values under rain-fed conditions. With a lack of data under irrigated conditions, these data under rainfed conditions can serve as a tool for producers considering straw removal. Johnson et al. (2006) determined the MSC values in soils with wheat in cropping systems from several literature reports. Most of these studies were conducted under rainfed systems where water inputs from precipitation were 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 rainfed environment, changes in SOC and other soil properties under rainfed 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 Removal

Because wheat and barley straws contain nutrients that are commonly supplemented as fertilizer in many soil systems, understanding the nutrient removal rates and the economics of this removal are important factors for producers to assess. The average concentrations of N, P, and K based on several published reports is 7.2, 1.0, and 10.1 g kg^{-1} for wheat, and 6.5, 1.0, and

13.2 g kg^{-1} for barley. The average N, P, and K masses removed in the straw produced from a wheat grain yield of 6,000 kg ha^{-1} average 53, 7.4, and 74 kg ha^{-1}, respectively. The average low prices for N, P, and K in the U.S. from 2000 to 2008 were \$0.48, \$0.24, and \$0.25 kg^{-1}, respectively (USDA-NASS, 2008). The average high prices for N, P, and K in the U.S. from 2000 to 2008 were \$1.38, \$0.86, and \$0.86 kg^{-1}, respectively (USDA-NASS, 2008). Using the average published nutrient concentrations and the high and low nutrient prices, the total N, P, and K nutrient costs were from \$6.65 to \$19.52 per Mg of wheat straw and from \$7.07 to \$21.95 per Mg of barley straw.

Straw removal will change the nutrient cycling dynamics of crop/soil systems compared to systems in which only grain is removed. Compared to grain, straw contains a lower proportion of P and N but a higher proportion of K for both wheat and barley. When straw is removed from fields, soil nutrient depletion (especially K) is more rapid compared to harvesting only grain. The overall increased removal of all nutrients will require understanding the changes in the overall nutrient/economic dynamics of the system. Understanding the changes in nutrient cycling with straw removal may also be useful in determining the nutrient balance of individual fields, farms, or even regions. Field measured nutrient concentrations and straw yields will vary, values presented in this paper are an example of potential nutrient removal and economic values.

Nutrient removal is a factor that needs to be accounted for when assessing the economics of straw removal. Under scientific-based nutrient management practices, nutrients in soils (obtained from soil sample analysis) are accounted for when determining nutrient recommendations. Increased fertilizer inputs will likely result where residue is removed over the long-term. The true value of the straw to a producer will depend on the need for nutrients in the production system. For example, under consistent straw removal and low K inputs, fields high in soil K may not need fertilizer inputs to replace the nutrients being removed in straw over the short-term. However, over the long-term nutrient levels in the soil will require inputs. Does the producer place a value over the short-term on the quantity of K removed in the straw? Another issue is how to place a value on N. In systems where grain residues remain in the field, most recommendations suggest adding extra N to account for the short-term immobilization of N. Therefore if straw is removed, theoretically, less N would be recommended for the following crop. However, data show that when straw is removed N is mined from the soil. How should the long-term removal of N in straw be addressed in the production/economic system? If accounting for the potential long-term impacts, the nutrient value should be included in the market value of the straw. Additional costs will likely need to be added depending on related factors such as residue harvest, transportation, storage and profit margin.

Straw Removal Effects in the Irrigated West

Rotations including wheat and barley in U.S. irrigated agriculture can be different compared to those summarized in this paper. For example, small grain rotations in the Pacific Northwest can include alfalfa, corn, potato, and sugarbeet. There is very little reported data that can be directly related to these irrigated rotations. To fully understand the impacts of crop residue management on soils, 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.

REFERENCES

Bahrani, M.J., M. Kheradnam, Y. Emam, H. Ghadiri, and M.T. Assad. 2002. Effects of tillage methods on wheat yield and yield components in continuous wheat cropping. Experimental Agriculture 38:389-395.

Biomass Research and Development Initiative. 2008. Increasing Feedstock Production for Biofuels: Economic Drivers, Environmental Implications, and the Role of Research [Online]. Available at http://www.brdisolutions.com/Site%20Docs/Increasing%20Feedstock_revised.pdf (Verified 22 Dec. 2008).

Bordovsky, D.G., M. Choudhary, and C.J. Gerard. 1999. Effect of tillage, cropping, and residue management on soil properties in the Texas Rolling Plains. Soil Science 164:331-340.

Campbell, C.A., G.P. Lafond, R.P. Zentner, and V.O. Biederbeck. 1991. Influence of fertilizer and straw baling on soil organic matter in a thick black Chernozem in Western Canada. Soil Biol. Biochem. 23:443-446.

Curtin, D., and P.M. Fraser. 2003. Soil organic matter as influenced by straw management practices and inclusion of grass and clover seed crops in cereal rotations. Aust. J. Soil Res. 41:95-106.

Follett, R.F., J.Z. Castellanos, and E.D. Buenger. 2005. Carbon dynamics and sequestration in an irrigated vertisol in central Mexico. Soil Till. Res. 83:148-158.

Johnson, J.M.F., M.D. Colemean, R. Gesch, A. Jaradat, R. Mitchell, D. Reicosky, W.W. Wilhelm. 2007. Biomass-bioenergy crops in the United States: A changing paradigm. The Am. J. Plant Sci. Biotech. 1:1-28.

Johnson, J.M.F., R.R. Allmaras, and D.C. Reicosky. 2006. Estimated source carbon from crop residues, roots and rhizodeposits using the national grain-yield database. Agron. J. 98:622-636.

Nelson, R.G. 2002. Resource assessment and removal analysis for corn stover and wheat straw in the Eastern and Midwestern United States – rainfall and wind-induced soil erosion methodology. Biomass and Bioenergy. 22:349-363.

Perlack, R.D., L.L. Wright, A. Turhollow, R.L. Graham, B. Stokes, and D.C. Erbach. 2005. Biomass as feedstock for a bioenergy and bioproducts industry: The technical feasibility of a billion-ton annual supply [Online]. US Department of Energy and US Department of Agriculture Available at http://www.eere.energy.gov/biomass/pdfs/final_billionton_vision_report2.pdf (Verified 22 Dec. 2008).

Tisdale, S.L., W.L. Nelson, J.D. Beaton, J.L. Havlin. 1993. Soil Fertility and Fertilizers. 5th Edition. MacMillan Publishing Company, New York.

Undersander, D.J., and C. Reiger. 1985. Effect of wheat residue management on continuous production of irrigated winter wheat. Agron. J. 77:508-511.

USDA-NASS 2008. Crops and Plants [Online]. Available at http://www.nass.usda.gov (Verified January, 2008).

USDOE-NREL. 2006. From biomass to biofuels [Online]. Available at http://www.nrel.gov/biomass/pdfs/39436.pdf (Verified September 24, 2007). USDOE-NREL, Golden, CO.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. 2004. Crop and soil productivity response to corn residue removal: A literature review. Agron. J. 96:1-17.

PROCEEDINGS
OF THE
WESTERN NUTRIENT
MANAGEMENT CONFERENCE

Volume 8

MARCH 4-5, 2009
SALT LAKE CITY, UTAH

Program Chair:
Grant Cardon
Utah State University
4820 Old Main Hill
Logan, UT 84322-4820
(435) 797-2278
Grant.cardon@usu.edu

Coordinator:
Phyllis Pates
International Plant Nutrition Institute
2301 Research Park Way, Suite 126
Brookings, SD 57006
(605) 692-6280
ppates@ipni.net