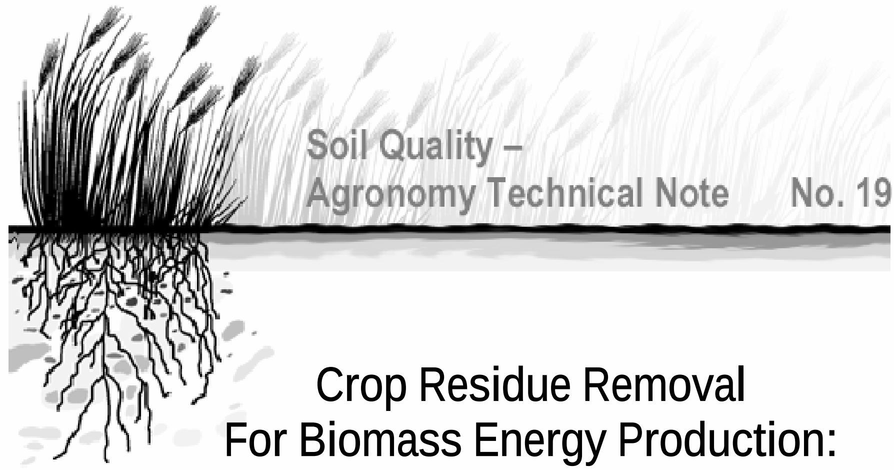
United States Department of Agriculture

NRCS Natural Resources Conservation Service

Soil Quality
National Technology
Development Team



Crop Residue Removal For Biomass Energy Production: Effects on Soils and Recommendations

Technical Note No. 19

August 2006

This is the nineteenth in a series of technical notes about the effects of land management on soil quality.

Written by:
Soil Quality National
Technology Development Team
200 E. Northwood St, Ste. 410
Greensboro, NC 27401
336-370-3331

soils.usda.gov/sqi

The promise of biomass energy

Concerns about the security and sustainability of fossil fuel use, coupled with advances in biomass conversion technology, have renewed interest in crop residue as a biofuel to partially meet our energy needs (Glassner et al., 1999). In light of the renewed interest in domestic production of biofuels and other biomass energy, can a portion of the more than 500 million tons of crop residue produced each year be used to meet some of our energy needs? The answer is not straightforward since crop residues perform many positive functions for agricultural soils that reduce erosion and promote sustainable production.

For commercial scale biofuel production, corn is receiving the most attention due to its concentrated area of production and because it produces 1.7 times more residue than other leading cereals based on current production levels (Wilhelm et al., 2004). Other high residue crops, such as rice and sugarcane, might contribute to biofuel production as a solution to residue disposal issues associated with their production (DiPardo, 2000; Wilhelm et al., 2004). Low residue crops, such as soybean, rarely produce enough residue to maintain adequate soil cover through the winter, and so are not receiving serious consideration as biofuel feedstocks.

Relatively low-cost harvest and abundance of crop residues make them competitive as gasoline additives (DiPardo, 2000). Since the rising cost of fossil fuel and related products increases the cost of agricultural production, most agree that one-pass harvest for grain and residue must become a reality to make residue-based biofuel production economically and energetically feasible (DOE, 2003). Once technology to produce ethanol from cellulosic materials is in place, it may be more efficient and the resultant fuel may have lower emissions than grain ethanol (Table 1).

Table 1. Comparison of Corn Grain Ethanol and Corn Stover Ethanol

Ethanol Feedstock	Net Energy Balance* (e_{EtOH} - $e_{production}$)	Percent reduction in GHG emissions/vehicle mile** E10	E85
Corn grain	25,000 Btu/gal	2%	25%
Corn stover	60,000 Btu/gal	9%	79%

*Net Energy Balance is estimated as the energy contained in 1 gallon of ethanol minus the energy required to produce it.
**Estimates of greenhouse gas (GHG) emissions from E10 (90:10 gasoline:ethanol) and E85 (15:85 gasoline:ethanol) as compared with conventional gasoline (Wang et al., 1999).

Benefits of crop residues (and the detrimental effects of removing them)

As a physical buffer, crop residues protect soil from the direct impacts of rain, wind and sunlight leading to improved soil structure, reduced soil temperature and evaporation, increased infiltration, and reduced runoff and erosion. While some studies suggest that plant roots contribute more carbon to soil than surface residues (Gale and Cambardella, 2000), crop residue contributes to soil organic matter and nutrient increases, water retention, and microbial and macroinvertebrate activity. These effects typically lead to improved plant growth and increased soil productivity and crop yield. The basic relationships between these effects are shown in Table 2.

Crop residue is managed using conservation tillage systems, such as no-till, strip till, ridge till, mulch till, and other reduced tillage methods (see NRCS Conservation Practice Standards 329, 344, 345, and 346). Most studies involving the effects of crop residues have compared no-till systems with residues to conventional tillage without residues, a presumed best case – worst case comparison, overlooking the interaction effects between tillage and residues. Karlen et al. (1994) found that 10 years of residue removal under no-till continuous corn in Wisconsin resulted in deleterious changes in many biological indicators of soil quality, including lower soil carbon, microbial activity, fungal biomass and earthworm populations compared with normal or double rates of residue return. Lindstrom (1986) found increased runoff and soil loss with decreasing residue remaining on the soil surface under no-till, with the study results suggesting a 30% removal rate would not significantly increase soil loss in the systems modeled. Reduction in these properties and populations suggests loss of soil function, particularly reduced nutrient cycling, physical stability, and biodiversity.

Table 2. General Benefits of Crop Residues to Soil Quality (after Larson, 1979)

Primary Effect		Secondary Effect		Tertiary Effect
Contributes to soil organic matter	⇒	Improves Chemical, Physical & Biological Properties	⇒	Increases yield and yield sustainability
Provides Physical buffer	⇒	Reduces raindrop impact and wind shear	⇒	Reduces soil erosion

Despite the many important benefits of crop residues, research shows some of their effects can vary. For example, some reports showed lower yields in systems with high crop residues due to increased disease or lower germination (e.g. Linden et al., 2000). Dam et al. (2005) reported poorer emergence under no-till corn with residues intact compared with residues removed and conventional till with and without residues, which they attributed to cooler soil temperatures and higher soil moisture associated with climatic conditions. Power et al. (1986) found increased crop yields for corn and soybean when residues were left on the soil surface compared with yields under residue removal in Nebraska. This yield effect was most pronounced in drier years, leading them to attribute yield increases to residue-induced water conservation.

Rate of residue decomposition varies by climate and crop, leading to varying amounts of erosion protection and organic matter additions to the soil. Due to these and other site-specific effects of residue on soil function, residue removal recommendations need to consider soil type, climate, cropping system, and management in order to protect soil quality while allowing for residue harvest for biofuel production.

For a more comprehensive review of the literature, see Andrews (2006).

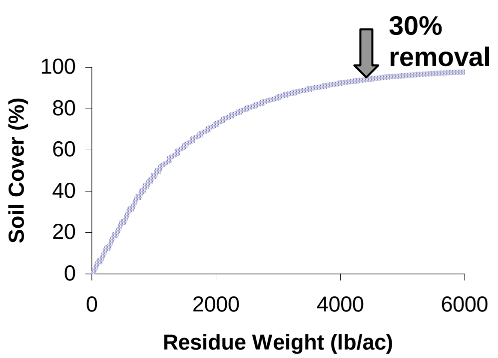


Figure 1. The relationship between percent of soil covered by residues after harvest and residue weight per acre for common small grains and annual legumes in the non-irrigated U.S. Northwest

Research considerations

Most studies examine residue removal based on weight of tissues removed at harvest, while management practices and conservation programs often concentrate on the percentage of soil covered by residue after planting the next crop. While they are related, ***a 30% residue removal rate is not the same as 70% soil cover, regardless of when soil cover is measured.*** Research by McCool et al. (1995) shows this relationship for small grains and annual legumes in the non-irrigated U.S. Northwest (Figure 1). In this example, a 30% (or 1800 lb/ac) removal rate results in 93% soil cover after residue harvest. The relationship between residue removal weight and resulting soil cover needs to be determined for that crop, if using published research recommendations to determine appropriate removal rates.

Many studies to predict residue removal effects on erosion have used the Universal Soil Loss Equation (USLE) or the Revised Universal Soil Loss Equation (RUSLE), with some assuming erosion to Soil Loss Tolerance (“T”) to be sustainable. Using RUSLE2 and the Soil Conditioning Index (SCI) is probably the most expedient method to estimate sustainable residue removal rates in the NRCS field office.

Nelson (2002) estimated the amount of corn and wheat straw residue available for harvest from all land capability class I-IV soils in 37 Eastern and Midwestern states by county. To accomplish this, the crop yield (with resulting residue production) required at the time of harvest to insure that T is not exceeded was estimated for each county utilizing RUSLE or the Wind Erosion Equation (WEQ), depending on whether water erosion or wind erosion posed the greatest risk of soil loss, using NRCS databases. RUSLE or WEQ was run using measured yield averages for each county to obtain estimates of actual residue production for a three-year period.

Nelson (2002) reasoned that subtracting the predicted amount of residue required to stay at or below T (calculated from the first set of analyses) from the amount of residue calculated from actual yield data would result in the amount of residue available for harvest. Some future hurdles to predict residue harvest potential from cropping systems include extending these results to all regions and soils, other crops, and extending the prediction to include more than just soil loss as a resource concern. To fully consider the soil quality impacts of residue removal, this method should also consider effects on soil organic matter, nutrients, biota, and future crop yield.

Recommendations

To be sustainable, residue must only be removed when soil quality will not suffer as a result. In some regions the combination of crop, management practice, soil, and climate work together to produce more than is needed to maintain soil health. In this case, excess residues could potentially be used for conversion to biomass energy. However, for many other cropping, soil, and climate combinations (especially in warm regions), residue production is inadequate even for basic soil protection (Parr and Papendick, 1978). It is important to discern in what systems residue harvest is possible, or even beneficial, and at what rates (Table 3).

Table 3. General Guidelines for Sustainable Residue Harvest (after USDA-NRCS, 2006)

Sustainable harvest amounts will vary by:	Residue harvest rates should DECREASE with:	Recommendations for sustainable residue harvest:
Management practice	Increased soil disturbance	Use no-till with cover crops
Crop & yield	Lower yield or lower C:N	Harvest high residue crops and only in good yield years
Climate	Warmer, wetter climate	Residue harvest in the US SE is high-risk
Soil type	Coarser soil texture	Heavy clay, poorly drained soils are good candidates
Topography	Greater slope	Use a variable rate harvester or stay off hillsides and eroded knolls

Determine Sustainable Residue Removal Rates – Sustainable removal rates will vary by region and management system, sometimes even with fields. Removal rates will need to be reduced as climates become warmer or more humid; for lower C:N residue; for lower yielding crops; as soil disturbance (e.g. tillage) increases; and as soils become coarser textured compared to the conditions in which most studies occurred (in the Midwest Corn Belt for no-till corn).

Tools like RUSLE2, WEQ, and the SCI are likely to be the most practical ways to predict safe removal rates to maintain erosion protection and soil quality. Similar to Nelson's calculations to estimate residue harvest potential from corn and wheat systems in the East and Midwest, conservation planners in the NRCS Field Office can use RUSLE2 to determine harvestable crop residue using expected yield (and associated residue production) from producer records or county averages. Trial or 'what if' runs can be made with reduced amounts of residue (simulating harvest), to determine what amount is required to hold soil loss to T and maintain a positive SCI. The weight of crop residue available for harvest would then be determined by difference.

Use Additional Conservation Practices – Other conservation practices such as contour cropping or conservation tillage must be used to compensate for the loss of erosion protection and soil organic matter seen with residue removal (Larson, 1979; Lindstrom et al., 1981). In many regions, cover crops are a viable alternative that offer soil protection and added organic matter. Green biomass, as with a cover crop, is considered to be 2.5 times more effective than crop residue in reducing wind erosion (in predictive models), especially if the residue is laying flat (McMaster and Wilhelm, 1997).

Consider Crop Alternatives – Where crop residues are required to maintain sustainable production, a more viable option may be crops grown specifically as energy crops, including herbaceous energy crops like switchgrass and short-rotation woody crops like hybrid poplar (USDA-NRCS, 2006). Being perennials, these crops require few field passes and little soil disturbance, resulting in low erosion rates. Paine et al. (1996) recommended growing these crops on marginal lands, such as highly erodible land (HEL), poorly drained soils or areas used for wastewater reclamation, which would avoid competition with food crops and increase the amount of arable land. A large amount of land in the Corn Belt is classified as HEL (Wilhelm et al., 2004) (Figure 2), presumably making this land unsuitable for residue removal but potentially viable for perennial energy crop production.

Perform Periodic Monitoring and Assessment – Regardless of the specific residue removal practice chosen, crop fields should be carefully monitored for visual signs of erosion or crusting. Periodic checks of soil organic carbon as part of soil fertility testing are also recommended. Removal rates should be adjusted in response to adverse changes: if erosion increases or soil organic carbon decreases, removal rates must be reduced to maintain soil quality.

Summary

Because of the important function of crop residues in erosion protection and overall soil quality, their sustainable use will only be accomplished through the use of site-specific harvest rates. Using approved erosion prediction tools can help determine acceptable harvest rates. New technologies for one-pass grain and residue harvest should include within-field variable harvesting rates so that removal guidelines can be applied. Additional conservation practices to control erosion and add soil organic matter will help alleviate negative effects of residue harvest. In the long term, dedicated energy crops, such as switchgrass or woody biomass, are likely to be the most viable option. Periodic monitoring and assessment of harvested fields, coupled with the above practices, will ensure that soil quality is not sacrificed in the name of renewable biomass energy.

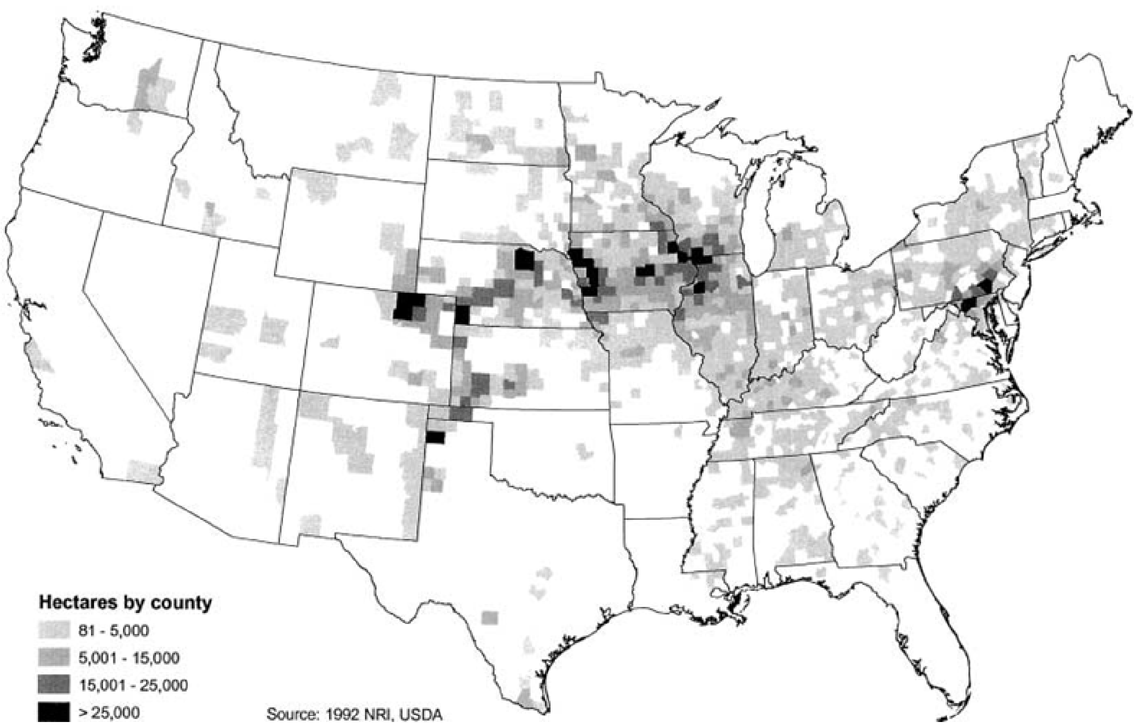


Figure 2. US Highly Erodible Cropland (USDA, 1995)

References

Andrews, S. 2006. Crop residue removal for biomass energy production: Effects on soils and recommendations [Online]. Available at http://soils.usda.gov/sqi/files/AgForum_Residue_White_Paper.pdf. USDA NRCS.

Dam, R.F., BB.Mehdi, M.S.E. Burgess, C.A. Madramootoo, G.R. Mehuys, I.R. Callum. 2004. Soil bulk density and crop yield under eleven consecutive years of corn with different tillage and residue practices in a sandy loam soil in central Canada. Soil and Tillage Research 84:41–53.

DiPardo, J. 2000. Outlook for biomass ethanol production and demand [Online]. Available at http://www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf (posted April 2000; verified 7 Oct. 2003). Energy Information Administration, Washington, DC.

Gale, W.J., and Cambardella, C.A. 2000. Carbon dynamics of surface residue- and root-derived organic matter under simulated no-till. Soil Science Society of America Journal 64(1):190-195.

Glassner, D., Hettenhaus, J. and Schechinger, T. 1999. Corn stover potential: Recasting the corn sweetener industry. CORE4 and CTIC. http://www.ctic.purdue.edu/Core4/StoverNCNU.pdf

Karlen, D.L., Wollenhaupt, N.C., Erbach, D.C., Berry, E.C., Swan, J.B., Each, N.S. and Jordahl, J.L. 1994. Crop residue effects on soil quality following 10-years of no-till corn. Soil and Tillage Research 31:149-167.

Larson, W.E. 1979. Crop residues: Energy production or erosion control? Journal of Soil and Water Conservation March-April: 74-76.

Linden, D.R., Clapp, C.E. and Dowdy, R.H. 2000. Long-term corn grain and stover yields as a function of tillage and residue removal in east central Minnesota. Soil and Tillage Research 56:167-174.

Lindstrom, M.J. 1986. Effects of residue harvesting on water runoff, soil erosion and nutrient loss. Agriculture, Ecosystems and Environment 16:103-112.

Lindstrom, M.J., Gupta, S.C., Onstad, C.A., Holt, R.F. and Larson, W.E. 1981. Crop residue removal and tillage: Effects on soil erosion and nutrient loss in the Corn Belt, U.S. Department of Agriculture.

McCool, D.K., Hammel, J.E. and Papendick, R.I. 1995. Surface Residue Management. Crop Residue Management to Reduce Erosion and Improve Soil Quality: Northwest. Papendick, R.I. and Moldenhauer, W.C., U.S. Department of Agriculture Conservation Research Report 40:10-16.

McMaster, G.S. and Wilhelm, W.W. 1997. Conservation compliance credit for winter wheat fall biomass production and implications for grain yield. Journal of Soil and Water Conservation Sept.-Oct.:358-363

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.

Paine, L.K., Peterson, T.L., Undersander, D.J., Rineer, K.C., Bartelt, G.A., Temple, S.A., Sample, D.W. and Klemme, R.M. 1996. Some ecological and socio-economic considerations for biomass energy crop production. Biomass and Bioenergy 10(4):231-242.

Parr, J.F. and Papendick, R.I. 1978. Crop residue management systems: New Perspectives for soil, water, and energy conservation. Crop Residue Management Systems. ASA Special Publication 31. Oschwald, W.R., Stelly, M., Kral, D.M. and Nauseef, J.H. Madison, WI, ASA-CSSA-SSSA, Inc.

Power, J.F., Wilhelm, W.W. and Doran, J.W. 1986. Crop residue effects on soil environment and dryland maize and soya bean production. Soil and Tillage Research 8:101-111.

USDA-NRCS. 2006. Resource effects of biomass energy production (in review). Conservation Issue Brief, USDA NRCS, May, 2006.

US DOE. 2003. Roadmap for Agricultural Biomass Feedstock Supply in the United States. DOE/NE-ID-11129. US Department of Energy, November.

Wang, M., C. Saricks, and D. Santini. 1999. "Effects of Fuel Ethanol Use on Fuel-Cycle Energy and Greenhouse Gas Emissions". Center for Transportation Research, Argonne National Laboratory. pp.1-32.

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