Biomass from Crop Residues: Cost and Supply Estimates. by Paul Gallagher, Mark Dikeman, John Fritz, Eric Wailes, Wayne Gauther, and Hosein Shapouri. U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report No. 819

Abstract

The supply of harvested crop residues as a feed stock for energy products is estimated in this report. The estimates account for economic and environmental factors governing residue supply. The supply results span major agricultural crops in four distinct cropping regions of the United States, taking into account local variation in cost-determining factors such as residue yield, geographic density of residues, and competition for livestock feed use.

Keywords: Crop residues, harvested residue, residue yield, supply estimates, soil quality, cropping regions, feedstock, biomass technologies, reduced tillage, forage.

About the Authors

Paul Gallaghner is in the Economics Department at Iowa State University, Mark Dikeman was in the Animal Science Department at Iowa State University, John Fritz is in the Agronomy Department at Kansas State University, Eric Wailes is in the Agricultural Economics Department at the University of Arkansas, Wayne Gauther is in the Agricultural Economics Department at Louisiana State University, and Hosein Shapouri is in the Office of Energy Policy and New Uses, USDA.

Acknowledgments

The authors thank Thomas McDonald and Dana Rayl West for the excellent editorial assistance, Wynnice Pointer-Napper for the final document layout, charts, and cover design.

300 7th Street, SW
Room 361 Reporters Building
Washington, DC 20024

February 2003

Contents

Summary

Biomass supply from crop residues can increase producer profits while maintaining soil quality, provided that reduced tillage and partial residue harvest are used appropriately. Corn Belt, Great Plains, and West Coast participation is possible with judicious selection of crops and management practices. Also, residues are probably the lowest cost form of biomass supply, but the range of costs is wider in the Great Plains than in the Corn Belt. The remaining regions, the West Coast, the Delta, and the Southeast, also have pockets with residue supplies and a wide variation in costs.

Crop residues have the potential to displace 12.5 percent of petroleum imports or 5 percent of electricity consumption in today's markets. Residues also have growth potential from improving crop productivity and declining livestock demands for forage. When residue supplies are included with some other agricultural sources, biomass supply from crop agriculture could account for an important share of our energy consumption. But further development of processing technology is still needed.

Biomass from Crop Residues
Cost and Supply Estimates

Paul Gallagher, Mark Dikeman, John Fritz,
Eric Wailes, Wayne Gauther, and Hosein Shapouri

Introduction

Harvested residues from annual field crops are suitable as a feedstock for some emerging industrial processes, such as the production of ethanol and plastics (Committee on Biobased Industrial Products, 2000). Some estimates suggest that crop residue quantities compare favorably with wood residues (Spelman, 1994); however, the economic and environmental factors governing residue supply have not been evaluated. The supply estimates presented here span major agricultural crops in four distinct cropping regions of the United States, taking into account local variation in cost-determining factors such as residue yield, geographic density of residues, and competition for livestock feed use. Specifically, residues are included in the estimation of potential industrial supply only if their removal by harvest would not result in excessive soil erosion. This is a necessary restriction because farmers' decisions and government policies will likely be consistent with soil conservation.

Subsequent sections of the paper look at the residue supply curves for major crops. First, estimation procedures and environmental constraints are reviewed. Then cost and supply estimates are presented for the major crop-producing regions of the United States. The results suggest that crop residues will be able to provide a moderate amount of the U.S. fuel supply with the advent of fully developed biomass technologies.

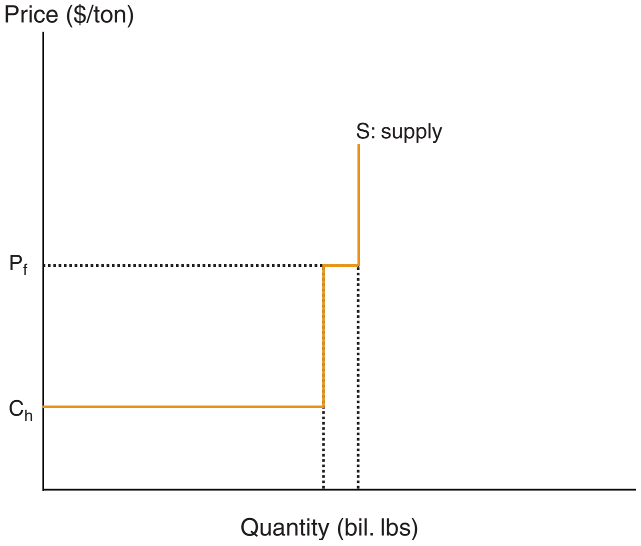
Farm Supply Function for Crop Residues: General Comments

Residues may be desirable raw materials because utilizing them does not require recovering land costs, already covered in the grain enterprise. The residue supply for the processing industry depends on opportunity costs at the farm level. The farm-level supply curve is a step function if residues are available for harvest (fig. 1). Initially, the harvesting cost of residue is the opportunity cost for unused residues. But residue often has a higher value when fed to livestock as forage. Therefore, a second step of the supply function may be defined by a higher feed value; all residue supplies would be diverted to industrial uses at the point when ethanol processors meet the price of cattle owners. Finally, residue supply increases in value when all harvested residue is used by industry.

The residue supply curve is an approximation for the acquisition cost by individual processing enterprises at the farm level. Processing plants within cash-grain areas might acquire unused residues at slightly above harvest cost. But plants in or near major livestock areas could acquire residues only if they offered a price at least equal to its value as feed. The processing plants' acquisition costs for residue will vary depending on crop yields and cattle populations.

Other factors may also impinge on the farm residue supply. For instance, some producers may require compensation for the reduction in grain yield stemming from reduced tillage. However, producers

Figure 1
Crop residue supply for industrial processing



without erosion problems will remain beyond the conservation margin with conventional tillage. Residue harvest in northern climates may require more harvest capital and timely labor supply due to the short harvest season. Elsewhere, harvesting capital requirements and costs may be lower if harvesting continues through the winter and processors provide harvesting services. In these situations, the harvesting capacity could match the monthly capacity of the processing plant.

Estimation Procedures

The usual econometric tools are not useful for estimating the supply of residues because substantial markets for these products do not yet exist. Specifically, there are no output and price data. Entry-point supply estimates are appropriate because the level of producer participation in residue harvest is the main supply adjustment. Individual firms or local supply areas are sorted with low-cost producers first and high-cost producers last. The capacity that corresponds to a particular entry price is included in supply when costs are covered. Elsewhere, entry-point supply analysis is used to analyze transport services in international trade (Shimojo, 1979) and for producer participation decisions in government programs in agriculture (Hoag and Holloway, 1991; Perry et al., 1989).

Two types of economic information are developed for each producer or local supply area. First, the height of the local supply function is analyzed with cost calculations. Second, a residue balance sheet identifies the output available at the cost threshold. Firms or groups of firms with particular types of outputs are ranked from low cost to high cost. All cost, output, and feed estimates are developed using county data, since agronomic conditions are uniform at this level. Data from 1997 are used for the baseline because the most recent Census of Agriculture supplements the annual data from the U.S. Department of Agriculture. County data are used to uncover the effects of variation in residue yield, density, and forage requirements on cost and supply.

Costs. Several costs determine the height of the farm supply curve for crop residues. First, the cost of harvesting residue is the opportunity cost of residue in cash grain areas. Cost estimates for chopping, baling, and on-farm hauling of crop residues are included. Because unused residues may have value (in that they reduce fertilizer needs or soil erosion), appropriate adjustments are included in cost estimates. Second, the residue market will reflect the forage value of residue and prices for the close substitute, hay, when the unused residue is exhausted in a local area. Quality discounts from the hay price are typical, and the extent of discounting depends on the type of residue. Third, the transport rate and density of available residues influence the costs of assembly and delivery to the plant.

Supply and Utilization Tables for Residues. The industrial supply of residue available at harvest cost is estimated by residue production, less forage demand. The residue used for forage is also available to industrial processors at prices above the forage value.

The residue production calculation is straightforward multiplication of area and yield. But environmental factors account for three types of supply restrictions: reducing yield, eliminating land from residue harvest, and using reduced tillage. The marginal land and agronomic practices for residue harvest are identified by evaluating erosion-residue harvest tradeoffs with representative soils and alternative production methods, as described in subsequent sections. Yield reductions associated with government conservation requirements or conservation tillage are also explained later.

Forage demand estimates at the local county level take into account cattle population, the daily forage requirements of various types of cattle, and the local availability of forage supplied by pasture. The daily forage requirements of various types of cattle are shown in table 1. These feed requirements are taken from the Committee on Beef Cattle Nutrition (1996) and Jurgens. The length of the grazing season is estimated at the State level (table 1b). The estimated growing season is defined when rapid growth degree day accumulations begin and end. The annual cattle forage demand is the annualized daily feed requirement, excluding the proportion of the year that cows pasture.[1]

Local hay and silage production is subtracted from the annual forage demand. The forage requirement not taken into account approximates residue demand by cattle.

---

[1] The details of pasture season length estimation and feed requirements by type of cow are discussed in a separate report, available from the author upon request.

Table 1—Cattle forage requirements by type of cattle

Type	Daily forage requirement
	Pounds/day
Beef cows	27.6
Milk cows	25.2
Beef replacement heifers	13.2
Milk replacement heifers	9.6
Bulls over 500 lbs.	30.0
Steers	5.8
Heifers	5.5

Table 1b—Length of grazing season, by State

State	No. days in grazing season
Arkansas	224
California	241
Colorado	153
Illinois	156
Indiana	154
Iowa	146
Kansas	175
Louisiana	257
Michigan	142
Minnesota	138
Mississippi	225
Missouri	185
Montana	160
Nebraska	157
North Dakota	137
Ohio	157
Oklahoma	202
Oregon	161
South Dakota	143
Texas	221
Washington	161
Wisconsin	136
Wyoming	140

Supply Areas, Transport, and Input Costs for Processing Plants

The main factors influencing the spread between farm costs and delivered plant costs are the density of residue, the capacity of processing plants, and local truck-hauling rates. It is important to account for local variation in transport costs. Otherwise, an area with sparse supplies of very low-cost residues might be mistaken for a low-cost region. Or an area with moderate yield and harvest cost but dense supplies might be excluded, mistakenly, from potential plant locations with low-cost biomass.

The transportation component of material costs increases with factory capacity because greater distances are traveled to secure supplies. The physical relationship between distance from the plant (r) and available supplies (Q) from one crop can be approximated by:

$$Q = (\pi r^2)dy,$$

which is the product of the area of a circle of radius r, πr^2, and the density of residue, dy. In turn, residue density is the product of residue yield (y) and the density of planted crops in the total area (d). For example, d=320 acres of residues/mi^2 in a county with half of the land in corn and maybe y=3 tons of residue/acre, giving a volume density of dy=960 ton/mi^2.

When $\tilde{Q}$ is set at the capacity of the processing plant, the maximum distance required by the plant can be obtained by rearranging

$$r^* = \sqrt{\tilde{Q}/(\pi dy)}.$$

For the cost-distance relationship, notice that the production obtained from a ring of a given distance from the plant is given by the product of the circumference of the circle, the width of the ring, and the density of residue $\Delta Q = (2\pi r)(dy)\Delta r$. The marginal cost of expanding the outer circle by the increment Δr is given by $C'(r) = P(r)(2\pi r)(dy)\Delta r$. P(r) is the price gradient function describing the price-distance surface—in a well-chosen location, the price gradient should be the sum of residue harvest and transport costs. With a linear price gradient, the total cost function

$$C(r) = \int_0^{r^*} P(r)(2\pi r)(dy)dr$$

becomes

$$C(r) = (dy)(2\pi)\int_0^{r^*}(P_o + tr)rdr = (\pi r^{*2})(dy)\left[P_o + \frac{2t}{3}r^*\right],$$

where t is transport cost in \$/ton/mile. The average input cost (AIC) is

$$\frac{C(r^*)}{Q(r^*)} = P_0 + \frac{2tr^*}{3}.$$

Hence, the spread between AIC and farm costs, 2tr*/3, increases with the transport rate and the maximum distance. In turn, the supply radius increases with plant capacity and declines with greater supply densities.

Multiple Supplies and Input Costs

When there are several different types of crop residues in an area, the farm supply function for crop residues would likely have several steps corresponding to the residue supplies of a particular crop. Residue costs vary from crop- to- crop because the yield and the opportunity values for fertilizer replacement are different. This section considers the determination of efficient supply areas when there are several types of crop residues.

Suppose P_{0i} is the harvest cost for crop residue i. Also, r_i is the radius of the supply area for crop i. Also assume that crop 1 has lowest harvest costs, crop 2 is second-lowest, and so on. A processor seeking the minimum cost input will expand the supply area so that the cost of marginal supply is equal for each type of residue. The conditions

$$\begin{aligned} P_{01} + r_1 t &= P_{02} + r_2 t \\ P_{01} + r_1 t &= P_{03} + r_3 t \end{aligned} \qquad (1)$$

identify the boundaries of supply area 2 and supply area 3 (r_2 and r_3) when the boundary of 1 (r_1) is given in the three-product case.

To determine the market areas for each type of residue, notice that capacity output must equal the sum of production from each residue type

$$\overline{Q} = \sum_i \Pi\, r_i^2 d_i y_i \qquad (2).$$

When there are three supply areas with radii r_1 , r_2 , and r_3, equations 1 and 2 above provide a set of three equations that can be solved for the radii of the market areas. The equations in 1 can be substituted into 2 to eliminate r_2 and r_3. Then the quadratic formula can be used to solve for the radius r_1 that has efficient boundaries and fills the plant capacity.

The case when higher cost residues are not used can be identified without recourse to Kuhn-Tucker conditions. For instance, the market border condition,

$$P_{01} + r_1\, t = P_{02} + r_2\, t\ ,$$

also identifies the utilization threshold for the second (or third) crop. Specifically,

$$P_{01} + r_1\, t = P_{02} \quad \text{when} \;\; r_2 = 0.$$

Generally, the supply radius for crop i when crop j is on the entry threshold (Rij) is

$$\begin{aligned} R_{12} &= (\, P_{02} - P_{01}\,)\,/\;\, t \\ R_{13} &= (\, P_{03} - P_{01}\,)\,/\;\, t \\ R_{23} &= (\, P_{03} - P_{02}\,)\,/\;\, t\,. \end{aligned}$$

Next, we can check whether the plant's capacity has been filled by the time an entry threshold is reached. First, calculate the outputs associated with the two-product and three-product boundaries

$$\begin{aligned} Q_2 &= \Pi\, R_{12}^2 d_1 y_1 \\ Q_2 &= \Pi\, R_{13}^2 d_1 y_1 + R_{23}^2 d_2 y_2 \end{aligned}$$

All three possible cases can be defined with entry points and associated outputs. First, a plant's capacity is filled with one crop before the second crop is used if $Q_2 > Q$. Further, a two-product supply area fills capacity if $Q_2 < Q < Q_3$. Finally, a three-product supply area is used if $Q_3 < Q$.

Equipped with a list of included crops and supply areas (r_1, r_2, r_3), the plant's residue costs can be defined. Specifically, the total costs of residue type i are

$$C(r_i) = (\Pi r_i^2)(d_i y_i)\left[P_{01} + \frac{2}{3} t r_i\right]$$

with linear transport costs. Also, the output produced using residues of type i are

$$Q_i = \Pi r_i^2 d_i y_i$$

Finally, the average input costs are defined by

$$AIC = \frac{\sum_i C(r_i)}{\sum Q_i}.$$

So average input costs depend on the average harvest costs and transport charges,

$$AIC = \overline{P}_0 + 2/3 t\bar{r} \;\; \text{where}\; \overline{P}_0 = \sum_i S_i \overline{P}_{0i},\ \bar{r} = \sum_i S_i\, r_i, S_i = Q_i / \sum Q_i$$

when several crops provide residue supplies, where S_i refers to the share of supply provided by crop residue i.

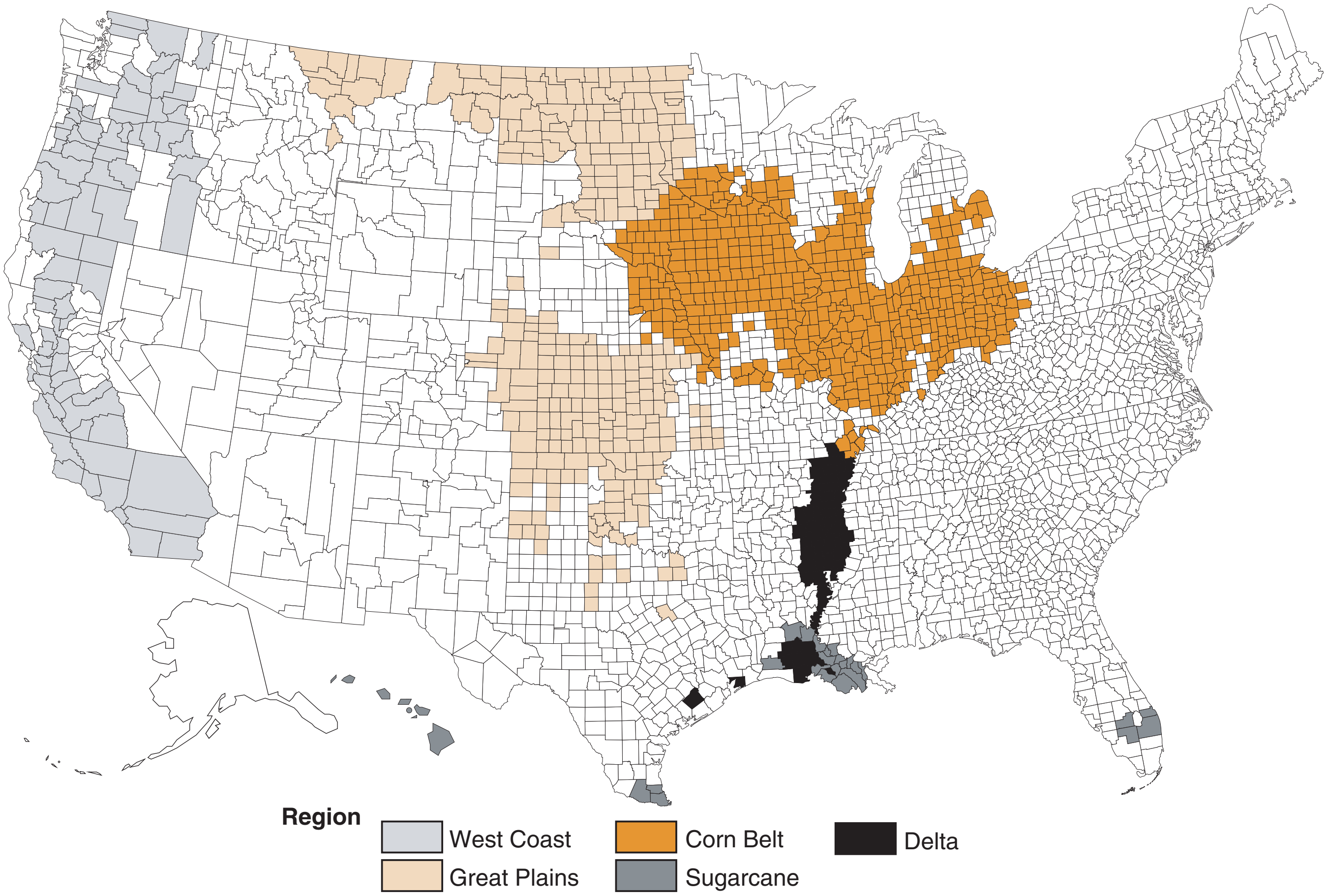
Regions

The regions of this study are areas with high-density production of a major crop that share common agronomic practices. County-level definitions of regions are used because only parts of most States should be included. County data also help to uncover the extent of variation in production costs. The four regions defined in figure 2 are the Corn Belt, the Great Plains, the West Coast, and the South.

The Corn Belt includes eastern Nebraska, southern Minnesota, Iowa, southern Wisconsin, Illinois, Indiana, southern Michigan, and eastern Ohio. The dominant crop choices in the Corn Belt are corn and soybeans. Only the corn residue, referred to as stover, occurs in sufficient volume for residue harvest.

The Great Plains includes North Dakota, northwestern Minnesota, parts of northern and eastern Montana, Colorado, western Nebraska, Kansas, Oklahoma, and a few areas of northern Texas. Throughout the region, wheat is the dominant crop choice. But there are three types of agronomic practices for wheat production and differing alternate crop choices in different parts of this region. In the south and the east side of the Great Plains, winter wheat is grown continuously; wheat is planted in the fall, harvested the following spring, and seeded again the next fall. Continuous wheat production occurs when there is adequate rainfall and good soil. In the arid western part of this region, a 2-year plant-and-fallow cycle is required; wheat is planted in the fall and harvested the following spring. But the land is not re-seeded until it has been left idle over a winter and growing season. The delay enhances available water and soil fertility. In the Northern Plains, spring wheat is planted in the spring and harvested in the fall. It is necessary to distinguish among these agronomic practices because erosion potential and

Figure 2
Crop residue regions



local crop substitution possibilities vary. In the Northern Plains, the main substitute crops are barley and oats. In the continuous wheat area, dryland corn and sorghum are the main alternatives. In the wheat-fallow region, the main substitute is sorghum or, where irrigation water is available, irrigated corn.

The West Coast region includes Washington, Oregon, and parts of northern California. The crop choices and agronomic practices are the same as in the Great Plains.

The Southern region is limited to counties that are important in rice and sugar production. In the Mississippi Delta, rice provides the potential for residue supplies. Rice production occurs in parts of five States, but Arkansas has about half of the output. Other areas along the Mississippi River, northeastern Louisiana, northern Missouri, and Mississippi share about equally in the remaining rice output. Southwest Louisiana, which lies near the Atchafalaya River is also a major rice area. Most of the cane sugar is grown in the Southeastern United States. Bagasse, the portion of the sugarcane stalk that remains after the sugar has been removed in the refinery, is a useful form of biomass that occurs in the course of the production and refinery process, especially in southern Louisiana and southern Florida.

Environmental Constraints

Residue supply estimates are built on the assumption of reasonable soil conservation policy and practice. For the Corn Belt, Great Plains, and West Coast, we evaluate soil erosion-residue harvest tradeoffs for some representative soil and climate conditions. Residue harvest on land in a particular soil erosion class is included in supply calculations only if erosion is below tolerance. Using the maximum erosion criteria, we can also identify a suitable tillage system by introducing more conservation-oriented systems, possibly until the tolerance criteria are met. We also evaluate the government conservation requirements for soil cover with reference to the tolerance level. For the Mississippi Delta Region, a potential supply restriction stems from the maintenance of wildlife habitat.

Long-term aspects of soil quality maintenance also deserve attention. For instance, concerns about carbon sequestation are sometimes mentioned in connection with residue harvest. Based on research that compared corn grain and corn silage production over a 35-year period, the soil carbon does seems not to depend on the presence of residues; rather it is closely related to the choice of tillage system (Reicosky et al., Gale and Cambardella). In this report, the UDSA conservation guidelines, equivalent to leaving the residues from a 35-bu/acre corn crop, are followed in the harvest calculations. Hence, a judicious combination of residue harvest and reduced tillage may jointly maintain soil carbon and increase producer profits. The land use and residue yield adjustments that seem consistent with sustainable production are discussed in detail below.

Erosion Management. Some residue should be left as a soil cover on land where residue is harvested. The Natural Resource Conservation Service requires that 30 percent of the field be covered in the spring. For corn, 1,430 lb/acre of chopped corn stover left in the fall fulfills that requirement. For wheat and other small grains, 715 lb/acre of fall residues satisfy the requirement including the loss of residues during the winter (Wischmeier and Smith). For winter wheat fallow, it is assumed that the winter loss occurs twice, so the minimum fall residue would be 1,020 lb/acre. Net residue yield estimates below leave at least the recommended amount of fall residue for a soil cover.

Further, residues should be harvested only from land where soil can be conserved. There is a tradeoff between residue remaining after harvest and erosion. But soil and other land characteristics influence the position of the tradeoff line. Tradeoff calculations use representative soil and climate conditions. Land is included in residue harvest when the erosion level with the government conservation requirement stayed below tolerance level. The tolerance level is defined for each soil type; typically it is between 3 and 5 tons/acre.

We calculated soil erosion estimates for representative soils from several land classes and alternative residue-cover schedules. Land quality was taken into account using the land classification devised by the Natural Resource Conservation Service of the U.S. Department of Agriculture. The classification includes a ranking for erosion potential (Klingebiel and Montgomery, 1961). Class I soils have no erosion (or other) use-limiting features. Class IIe soils have moderate potential for erosion. Higher classes, IIIe to VIIIe, have increasing slope, less-durable soil structures, and increasing soil erosion potential. Water erosion calculations used the universal soil loss equation (Renard et al. 1993, and Hawkins et al. 1995). For wind erosion in the Great Plains, procedures given by Skidmore and Woodruff were employed. Additionally, several tables from Natural Resource Conservation Service Manuals were used for erosion estimates at a given location (e.g., Natural Resource Conservation Service, Kansas (1982)). Interpolated value of C, the annual climate factor, and I, the erodibility soil factor, were required for each location.[2]

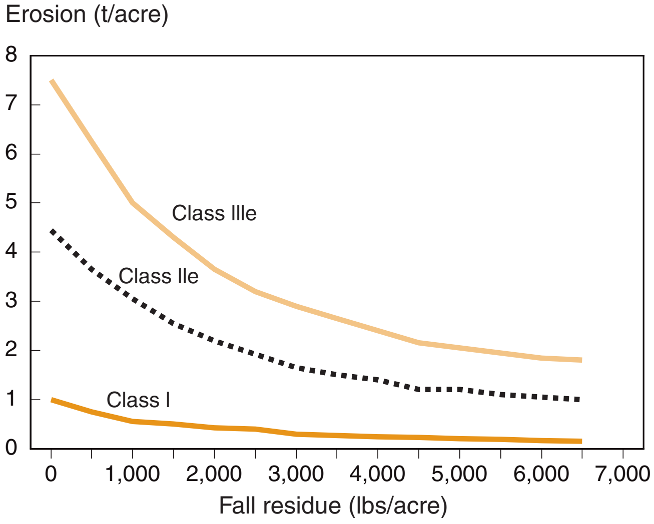
Finally, reduced tillage methods may be required for soil conservation. For corn, a 9.5-percent reduction of yields was imposed assuming everyone switches to mulch till, a reduced tillage method, in the Corn Belt. In lower moisture environments like eastern Kansas, however, the evidence suggests that there is not a yield reduction, since the 9.5-percent reduction will lead to conservative stover yield estimates. For wheat and other small grains, no-till farming was assumed throughout this reported tradeoff analysis, but a yield discount was not required.

Corn Belt. Figure 3 illustrates corn crop residue erosion tradeoff thresholds for three different land classes. The soil erosion-cover tradeoff with three soil classes is shown. The Class I and Class IIe soils were used in a study of corn production at Ames, a mid-Iowa location, and Chariton, a southern Iowa location (Park, 1996, p. 74). The Class I soil is Harps with 0-2 percent slope. The Class IIe soil is Clarion with 2-5 percent slope. The Class IIIe soil is Clarinda with 5-9 percent slope.

The Class I soil has no use-limiting features, and virtually any residue harvest gives soil erosion that is less than tolerance (5 tons/acre). Similarly, erosion remains below tolerance on the Class II soil provided that the government's guideline is met. But higher Classes, IIIe to VIIIe, have increasing slope, less durable soil structures, and increasing soil erosion potential. A 50 percent stover harvest would be marginally within the tolerance on the Class IIIe soil. Subsequent calculations exclude land from Classes III and higher from the residue harvest.

Figure 3

Corn stover-erosion tradeoff for corn in the Corn Belt (water erosion)



Great Plains. Our wind and water erosion estimates were based on Hayes's representative wheat-fallow case in western Nebraska. His estimate for the reduced (mulch) till system left 25 percent of the post-harvest residue on the soil at the subsequent planting. The baseline calculations also included wind strips with an unsheltered distance of 2,000 feet.

After replication of the base case, erosion estimates were adjusted for other wheat-fallow locations. Specifically, we used a soil type for western Kansas in the water erosion equation; and the wind erosion estimates feature the local Kansas values of C and I. Next, we introduced a no-till assumption. The no-till system estimates use the same projections for over-winter loss of residue given in the previous water erosion calculations, namely, 30 percent of fall residue is lost by springtime (Wischmeier and Smith). Using this over-winter loss figure and assuming that none of the post-harvest residue is destroyed through tillage, 70 percent of unharvested residue is left at springtime for continuous cropping or, in wheat-fallow systems, 49 percent of residue is left at planting time. In continuous planting estimates for eastern Kansas and northwestern Minnesota, the fallow year was excluded and local C and I values were used. Finally, the timing of planting and harvesting was modified for spring wheat.

Erosion-residue tradeoffs were calculated in representative cases for each major crop and cultivation method. For continuous winter wheat, a Reading silt-loam soil from Chase County was chosen as a typical soil type from eastern Kansas because it is common in this area.

---

[2] C measures the erosive potential of wind and soil moisture, expressed as a percent of the C-factor for Garden City, KS. I measures erosion from a given type of soil in a field with reference wind exposure and tillage conditions when C=100 (Soil Conservation Service, Iowa). Specific values used in the tradeoff analysis are C=20 and I=48 for corn, sorghum, and continuous winter wheat in Chase County, KS; C=30 and I=48 for spring wheat in Norman County, MN; and C=70 and I=48 for winter wheat/fallow in Ford County, KS.

Reading Class I soil has a 0-2 percent slope and the Class II soil has a 2-4 percent slope. For the winter wheat-fallow area, Harney silt-loam soil from Ford County in western Kansas was used. The most common Harney soil has a 0-2 percent slope. Corn and sorghum erosion estimates are also based on Reading and Harney soils. For spring wheat, a Kittson soil and a Barres soil from Norman County in northwest Minnesota approximate typical situations. Class I Kittson soil has a 0-2 percent slope and Class II Barres has a 3-5 percent slope.

The inclusion criterion is that the sum of wind and water erosion rates are within tolerance after a residue harvest. The charts in fig. 4 depict the harvest margin. Generally, a substantial residue harvest is consistent with erosion rates moderately below tolerance. For continuous winter wheat on Class II land (fig. 4a), the total erosion rate is about 3 tons/acre with a 715 lb/acre residue cover, which is below the 5 ton/acre tolerance. For spring wheat on Class IIIe land (fig. 4b), the total erosion rate is about 6 ton/acre with a 750 lb residue cover, which is near the 5 ton/acre tolerance. For winter wheat/ fallow on Class II land, the erosion rate drops to the 5 ton/acre tolerance when a fall residue of about 1,500 lb/acre is left after harvest (fig. 4c).

Thus, harvest of wheat residues up to the 715 lb/acre government recommendation (required to comply with soil-cover regulations) is suitable for continuous winter wheat in land Classes I or II. Similarly, removing residue for spring wheat and leaving only the government's minimum cover appears sensible for land in Classes I, II, or III. A partial harvest, which would leave at least 1,500 lb/acre of residue cover, is indicated for the wheat-fallow tradeoff on Class II land in western Kansas. In the last case, the 30-percent loss is a critical assumption for the marginal results. Slightly lower residue losses move the Class II wheat-fallow case into a higher harvest margin.

Erosion estimates for sorghum and corn on the Class I land in eastern Kansas are also presented in figures 4d and 4e. First, sorghum harvest is at the 5-ton/acre tolerance with the 1,430-lb/acre cover. Second, the corn estimate falls below tolerance, unless 2,500 lb/acre of residue remains. Wind erosion is the limiting factor in both of these cases. Thus, residue harvest on Class I land planted to corn or sorghum is suitable; however, for corn, the unharvested residue should exceed the minimum government allowance.

Delta. Water erosion is not a problem on the flat land of the Mississippi Delta, thus the standard Natural Resource Conservation Service recommendation for soil cover is not relevant to the flat soils in the Mississippi River Basin. But fermenting rice straw provides food for migrating waterfowl (Young). Residue harvest, up to the point when the food needs of migrating waterfowl are met, does not present a conflict. Ideally, estimation of waterfowl demands would depend on the duck population that travels through the Delta, how long they stay in the Delta region, and how much they eat in a day. Until these estimates become available, a partial residue harvest may be best.

Southeast. Sugarcane bagasse is part of the raw sugarcane stalk; so harvest and transport of bagasse to the refinery already occurs as part of the harvesting process. Thus, using bagasse has no change on soil conditions as it is already being removed.

A Harvest Cost Function

In developing general cost function, we noticed that some costs are constant on a per-acre basis while others are constant on a per-unit output basis. We used the same cost parameters for all counties and crops; however, the residue yield and fertilizer replacement rate vary across crops and counties.

Direct harvest costs are approximated by machinery replacement and operating costs for harvesting hay in large round bales. The cost estimates allow for three operations: chopping, baling, and on-farm transportation. Field operation costs for chopping and baling are based on estimates from the Society for Agricultural Engineers. Capital replacement cost estimates were provided by Cross and Perry. Lazarus adapted these cost studies for 1997 conditions. First, estimates for fixed costs are used as reported. Similarly, the reported operating expenses, \$1.47/acre for chopping and \$4.63/acre for baling, are also used. Reported labor requirements and the local farm wage are important components of the operating expense estimates.[3] The chop and bale costs are all fixed on a per-acre basis. The cost of moving the bales to a convenient

---

[3] The labor requirements for the chopper and the baler are the same. The calculation is:

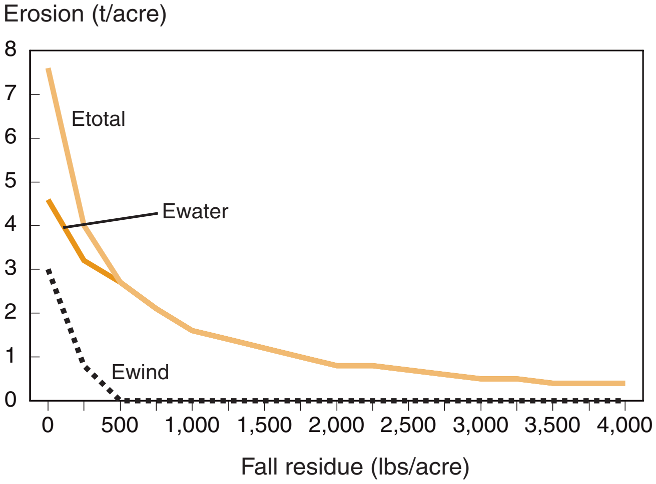
$$\frac{1 \text{ mach hr}}{4.65 \text{ acre}} \text{ x } \frac{1.1 \text{ worker hr}}{1.0 \text{ mach hr}} \text{ x } \frac{\$7.76}{\text{worker hr}} = \frac{\$\ 1.83}{\text{acre}}$$

Local variation in the farm wage was investigated but had little effect on harvest cost.

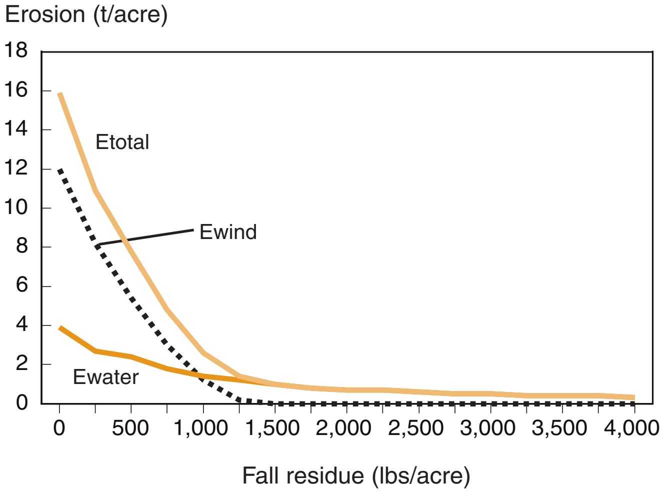
Figure 4

Great Plains crop residue erosion tradeoffs

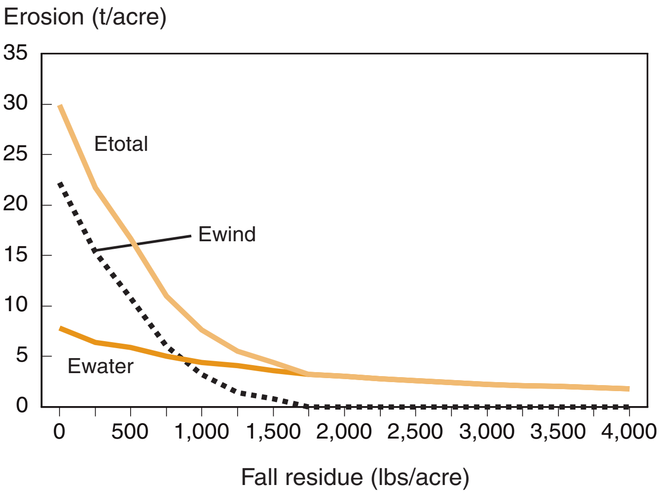
4a—Eastern Kansas, Class II, continuous winter wheat



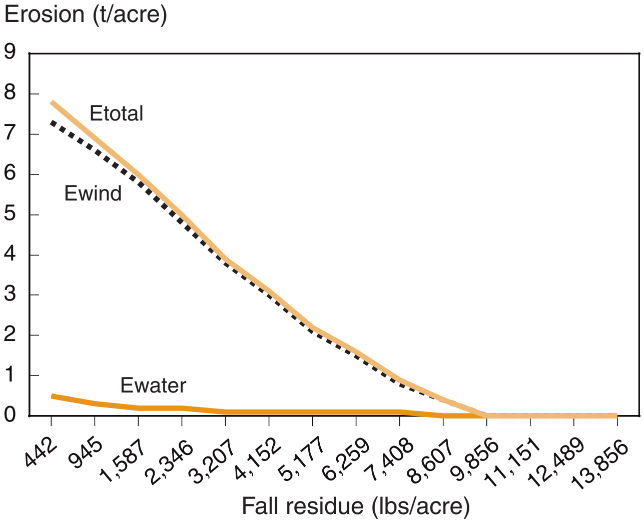
4b—Minnesota, Class IIIe, spring wheat



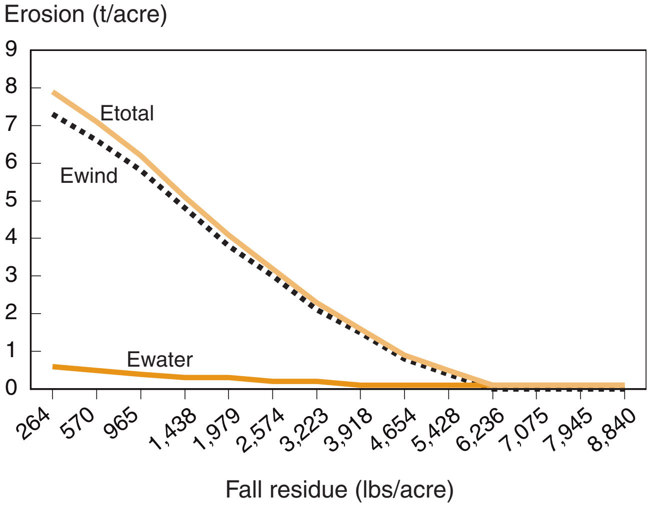
4c—Kansas, Class IIe, winter wheat-fallow



4d—Corn, Class I



4e—Sorghum, Class I



site for on-farm storage is taken from Duffy and Judd. The farm haul costs are fixed on a per-ton basis.

Indirect fertilizer costs account for the additional needs when residues are harvested. Unused residues provide some phosphorous, potassium, and nitrogen when left for the subsequent crop. Nutrient content tables for the residues of major crops (corn, sorghum, barley, oats, wheat, rice, bagasse) are available (Bath et al.). These tables include direct estimates of phosphorous (P) and potassium (K). The nitrogen (N) estimate was developed using a protein conversion factor from Russell. The costs of replacing fertilizer associated with residue harvest in 1997 are: $6.466 per ton for corn, $4.988 per ton for wheat, \$5.916 per ton for sorghum, \$7.491 per ton for barley, \$7.858 per ton for oats, \$5.42 per ton for rice, and \$3.95/per ton for sugarcane bagasse. These costs vary because fertilizer and nutrient content vary. For crops of the Midwest, fertilizer replacement costs vary about 50 percent from wheat to oats.

A harvest cost function that holds for all crops and counties in 1997 depends on the government conservation allowance (R, in dwt/acre) and the gross stover yield (Y_g, in dwt/acre). The cost estimate below defines the determinants of stover costs (C, in \$/dwt):

$$C = \frac{15.93}{Y_g - R} + F_i$$

The first term shows all of the costs that are constant on a per-acre basis. Specifically, chop and bale costs are related to trips across the field. So chop and bale costs on an output basis are inversely related to yield. The second term contains all costs that are constant on a per-unit output (ton) basis. On-farm hauling costs (\$1.18 per ton) are constant on an output basis because activity varies with the number of bales hauled. Fertilizer replacement costs, given above, are also proportional to residue yield. The second term is the sum of on-farm hauling and fertilizer costs. It varies from commodity to commodity depending on the fertilizer value.

The gross yield estimates are calculated from county average yields using the biological relationships. For instance, corn stover constitutes 55 percent of the dry matter of the corn plant (Aldrich et al.; Park)[4]. Residue-yield relationships for other Midwestern crops are taken from Plaster; Khush gives estimates of the rice, straw, grain-yield relationship; and Paturau provides bagasse yields from sugarcane.

Cost Estimates

A summary of cost estimates is given in table 2. Harvest and transport costs for typical situations are given. These examples indicate the range of plausible harvest costs and processing plant sizes.

Harvest costs for dominant crops in important production regions indicate the situation under good circumstances. Estimates are based on the harvest cost function. Cost differences across commodities and locations stem from variation in yield, conservation allowances, and opportunity values. Corn clearly has the lowest cost, especially with the exceptionally high yields from irrigated corn in the Great Plains. Harvest costs for some other major crops of the winter wheat area, wheat and sorghum in Riley County, KS, are slightly higher, at about \$16 per ton. In the spring wheat area, residue costs for wheat, barley, and oats are higher yet, in the \$17-19 per ton range. Rice costs include a substantial opportunity value reported by Wailes. Consequently, overall harvesting, fertilizer replacement, and opportunity costs total about \$20 per ton because a large opportunity value for forgone hunting rights is included. Finally, the winter wheat-fallow combination in Ford County, KS, is the highest cost form of residue due to the synergistic effects of low yields and high conservation requirements. Details of the harvest cost calculations are given in appendix tables A1-A10.

Transport costs depend on the density of crop residues, the size of the processing plant, and a given hauling rate. Transport cost estimates can be specified using plausible biomass plant capacities and typical density conditions. For instance, for Story County, IA, density is dy = 889.4 ton/mi^2, enough to support a very large ethanol plant ($\tilde{Q}$ = 2.9 million tons of residue) with moderate transport costs of about \$2.15 per ton. But the transport-cost differential between the large plant and the small plant increases rapidly when the supply density falls below dy=500 per ton/mi^2. Moderate transport costs are given in table 2 with a mid-sized ethanol plant in the spring wheat and rice areas, where residue density is mid-range. The lowest density in table 2, Riley County, KS, gives moderate transport costs with an electric plant much smaller than the mid-sized ethanol plant. Ultimately, a full analysis of economies of scale should be conducted. Nonetheless, these estimates show that crop residues would be available to processing plants in the range of \$14-\$30 per ton for all major field crops and regions.

Sugarcane bagasse is an exception to the harvest cost function. The harvest, transport, and fertilizer replacement costs for bagasse are associated with the primary sugar crop. Hence, the costs of harvesting and delivering bagasse to the plant are essentially zero.

Feed Value Estimates

Multiple steps in the residue supply curve can occur because livestock feed value varies with the type of

---

[4] Lipinski et al. use a slightly lower estimate for the stover component of the corn plant's dry matter (p. 106). But Park's recent experiments in Iowa confirm Aldrich's calculations.

Table 2—A summary of residue harvest and transport costs

Commodity	Location	Harvest cost		Residue density	Transport cost	Total cost
		$/ton		*t/mi ^{2}*	*$/t*	*$/ton*
				Type of plant		
Corn	Story County, IA	12.73		889.4	2.15	14.88
				Large ethanol		
Winter wheat, continuous	Riley County, KS	15.66		28.47		17.52
Sorghum		16.6		12.36		18.46
			sum	40.83	1.86	
				Electric		
Winter wheat, continuous	Ford County, KS	20.97		26.38		24.36
Winter wheat, fallow		29.78		45.28		33.17
Sorghum		16.73		0		20.12
Corn		12.43		0		15.82
			sum		71.66	3.39
				Ethanol		
Spring wheat, continuous	Norman County, MN	19.42		246.3		21.00
Barley		17.34		77.8		18.92
Oats		18.56		3.96		20.14
			sum	328.06	1.58	
				Ethanol		
Rice	Arkansas County, AR	20.32		283.24	1.70	21.90
				Ethanol		
	Transport cost ($/ton/mile)			0.1		

Plant input requirements (tons)100,000 electric plant
581,000 ethanol plant
2,900,000 large ethanol plant

residue. In turn, the livestock feed value varies with the total nutrient content and protein content of the residue. The hay price discount formulas of Stohhbehn and Ayres were used for residue feed value estimates. Also, a recent feed composition table gives the components present in various types of residues (Bath et al.). The estimates in table 3 vary widely, ranging from about $6 per ton for sugarcane bagasse to $43 per ton for sorghum stover. The variation in feed values reflects differences between residues in protein content.

Table 3—Cattle feed value by type of residue

Type	Value
	Dollars/ton
Corn stover	41.90
Sorghum stover	42.51
Wheat straw	21.21
Barley straw	32.09
Oat straw	34.25
Sugarcane bagasse	6.31
Rice straw	25.10

Supply Curves

Supply curves are constructed assuming that producers in a county will enter the market at the breakeven point where the price of residue equals the harvest cost. Variation in yields around a region will be an important reason for supply variation. The supply curves in figure 5 were developed using a two-step procedure. First, the county data were sorted on the computer by cost, tracking the associated net residue supply volume for each county. Then the quantities were cumulated, giving the total amount available in local residue markets at a given price.

Figure 5a gives the Corn Belt farm supply curve for corn stover. It suggests a highly elastic response at the farm level. If prices vary by little more than $2 per ton, ranging from about $12 to $14.50 per ton, the supply would go from zero to about 90 percent of the available stover supply (180 billion pounds) in the Midwest. Large plants have greater input cost variation than smaller plants reflecting variations in both yield and the geographical density of corn supplies. In a $6 per ton range from about $16.50 per ton to $22 per ton, the supply ranges from zero to about 90 percent of available stover. Finally, a 10-percent increase in the stover volume (not shown) is available at a much higher price of $42 per ton, the price of bidding these residues away from use as livestock feed. The diagram includes transport costs for a small ethanol plant and a large ethanol plant, respectively. The difference between the cost curves for a large plant and a small plant starts at about $2.50 per ton. It widens rapidly above 175 million pounds due to locations with exhausted high-density corn supplies.

The analysis for residue supply in the Great Plains is more complex due to the various costs of residue sources. Prices in the residue supply curve (fig. 5b) are the average input costs for a plant that follows the least-cost rule for use of inputs. Corresponding quantities come from the efficient market areas. Other supplies are available at the higher cost after efficient market areas are depleted.

Figure 5a

Corn Belt crop residue supply

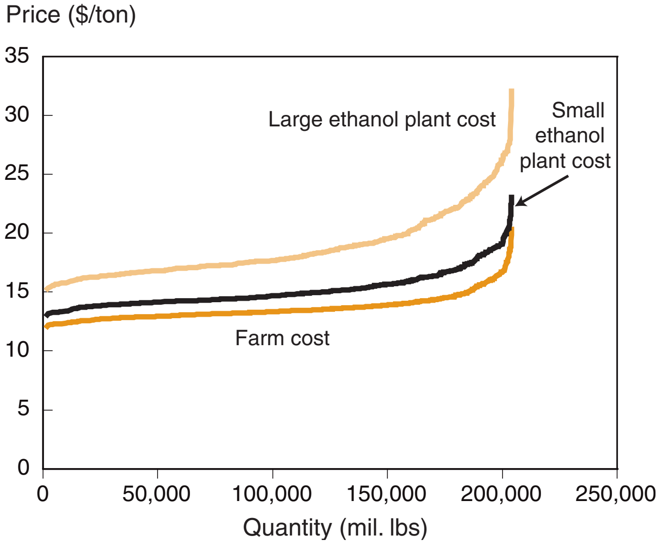
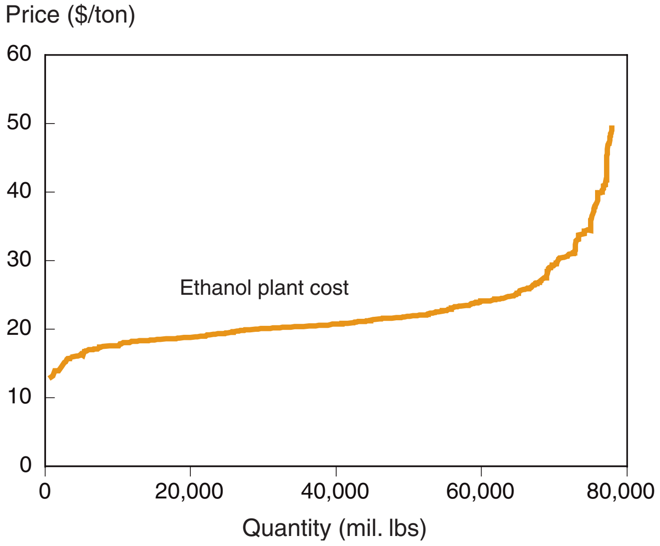


Figure 5b

Great Plains crop residue supply



The Great Plains supply curve (fig. 5b) includes the transport charges associated with a middle-sized ethanol plant. Crop residues would become available at about $14 per ton; at about $35 per ton, approximately 90 percent of the residue supplies would become available to the market. The increasing input costs reflect declining residue yields, increasing conservation requirements, use of wheat feed residues, and declining density of available residues.

The West Coast supply curve (fig. 5c) includes the transport charges for an electric-biomass plant. The initial concave shape indicates that there is a pocket where concentrated low-cost residue is available. Otherwise, the wide range of supply prices occurs for all the same reasons given for the Great Plains. The rightward shift at $42 per ton reflects the diversion of residues from animal feed to industrial supply.

The Delta supply curve (fig. 5d) is flat; most of the straw would become available within a range of about $20-25 per ton. The supply curve is flat because the yield and density conditions are uniform in the rice area.

In the Southeast, sugarcane bagasse is burned for energy in sugar refineries. The bagasse in cane provides slightly more energy than the modern plant requires: 100 tons of sugarcane produces 25 tons of bagasse (49 percent moisture mill run) and 9 tons are not needed for sugar processing (Paturau). Some modern facilities also install

Figure 5c

West Coast crop residue supply

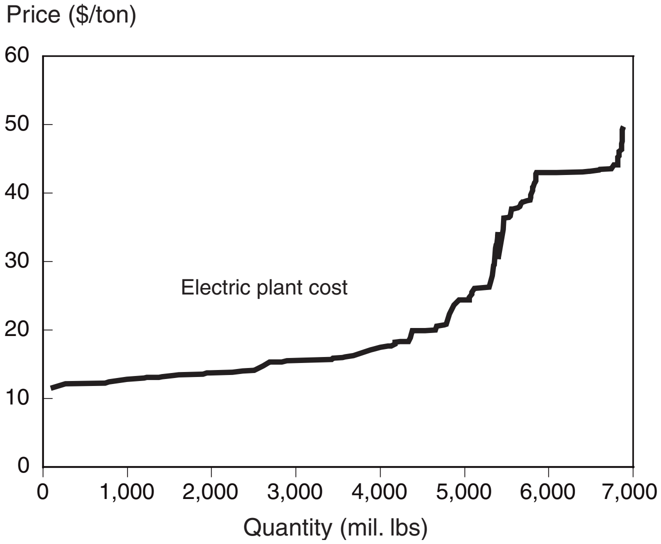
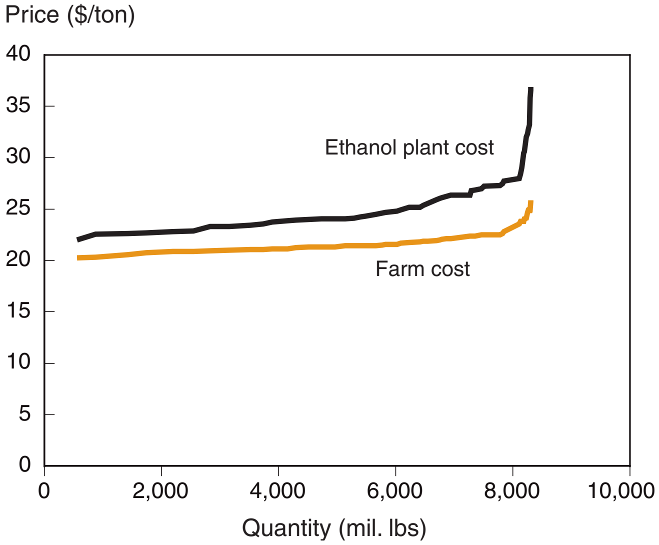


Figure 5d

Delta crop residue supply



generating equipment and sell electricity by burning the surplus. Other manufacturers must pay more than the opportunity value of bagasse in sugar refining before it will be supplied to others.

The opportunity value of heat from natural gas indicates the market supply price. The breakeven price for burning bagasse or natural gas with the same profit is

$$P_b = P_n Q_n / Q_b,$$

where P is price, Q is quantity, n is natural gas, and b is bagasse. For the 1997 baseline, the breakeven bagasse price is $34.65 per ton. Supplies will be available outside the refinery if the bid exceeds this breakeven price. The breakeven price is estimated from:

$$P_b = \frac{\$2.02}{10^3\,\mathrm{ft}^3},\ \text{conversion}: \frac{44.4310^3\,\mathrm{ft}^3\,\mathrm{n}}{1\mathrm{m.ton}},$$
$$Q_n / Q_b = \frac{1\mathrm{m.ton\ n}}{2.59\mathrm{m.ton\ b}}$$

Overall, the bagasse supply price is on the high side for crop residues. Its price compares more closely to livestock feed than to other biomass crops.

Biomass Supply and Capacity

Supply and utilization tables are useful for evaluating the supply potential of crop residues. Table 4 summarizes the regional supply situation. Net production includes conservation adjustments to yield and erosion-based restrictions required for the harvested area. Feed use indicates livestock demand minus hay supplies. Industry supply refers to unused residues that would be available to a biomass processing industry at a price near the harvest cost.[5]

The total biomass supply ranges from 297 to 313 billion pounds, depending on the price level. Corn Belt residues account for two-thirds of available residues. But the Great Plains account for nearly a quarter of available supplies. The other regions provide pockets of low-cost crop residues.

If the trends of the last two decades continue, growth should occur in the crop residue resource due to increased crop yields and declining livestock demand for forage. First, a repeat of crop productivity growth of 56 percent over the last two decades would account for another 170 billion pounds of crop residues. Also, the 10-percent decline in cattle populations of the last two decades could account for another 75 billion pounds of available biomass in another two decades. Hence, the biomass residue supply could grow to about 500 billion pounds during the next two decades.

Existing residue supplies could also make a difference in U.S. energy markets. Tomorrow's biomass ethanol technology could displace petroleum inputs (Gallagher

---

[5] State-level estimates of the supply and utilization tables are given in appendix B.

and Johnson). The petroleum displacement with all crop residue supplies is:

$$313 \text{ bil lb res} \times \frac{1 \text{ gal ethanol}}{.0083 \text{ ton res}} \times \frac{1 \text{ ton res}}{2{,}000 \text{ lb res}} \times \frac{1 \text{ bbl}}{42 \text{ gal}} \times \frac{0.84 \text{ bbl oil}}{\text{bbl}} = 0.377 \text{ bil bbl oil.}$$

Hence, ethanol processing from residues could displace 12.5 percent of U.S. petroleum imports in the 1997 baseline year. Alternatively, electricity displacement could occur with today's biomass conversion technology. Using the crop residue/electricity yields from Larsen, the electricity equivalent of the residue capacity is:

$$313 \text{ bil lb res} \times \frac{1 \text{ kWh}}{.000998 \text{ mt res}} \times \frac{1.1 \text{ mt ton res}}{\text{ton res}} \times \frac{1 \text{ ton res}}{2{,}000 \text{ lb res}} = 172.4 \text{ bil. kWh}$$

Hence, biomass electricity from residues could physically account for 5 percent of U.S. electricity consumption. However, energy displacements refer only to possibilities at present. The biomass ethanol technology is still under development. Biomass electricity processing is in operation in Denmark but may succeed in the United States only with high rates of utilization and local markets for byproduct heat.

Summary and Conclusions

This study has examined biomass supply from crop residues, taking into account cost and environmental factors. First, the analysis suggests that reduced tillage and partial residue harvest may maintain soil quality and increase producer profits. Corn Belt, Great Plains, and West Coast participation is possible with judicious selection of crops and areas. Second, residues are probably the lowest cost form of biomass supply. Throughout the Corn Belt, residue costs have a narrow price range, from $16 to $18 per ton, even after making allowances for delivery to a large plant. The range of costs is wider in the Great Plains due to diverse growing conditions, conservation requirements, and forage demands. The eastern section of the spring wheat area has extensive residue supplies at moderate costs. Also, the eastern section of the winter Wheat Belt has a cost advantage when feed grain residues, wheat straw, and residues diverted from feed are combined. The remaining regions, the West Coast, the Delta, and the Southeast, have pockets with residue supplies.

Crop residues are a low-cost resource with the potential to displace 12.5 percent of petroleum imports or 5 percent of electricity consumption in today's markets. The residue resource also has growth potential from crop productivity and declining livestock demands for forage. Taken with other potential sources, like Conservation Reserve Program (CRP) and hay land, biomass supply from crop agriculture could provide a substantial share of U.S. energy consumption. The agriculture sector can benefit from an increased presence in energy and industrial product markets, given steady productivity growth and stagnant traditional markets.

Table 4—Biomass from crop residues: Supply and capacity for 1997 baseline

Region	Net residue production	Feed use	Industry supply
		Mil lbs.	
Corn Belt	207,199	23,786	197,844
Great Plains	81,040	9,994	71,042
West Coast	7,377	2,573	4,805
Delta (Rice)	10,435	1,168	9,246
Southeast (Sugar bagasse)	7,114	0	7,114
Total	313,165	37,521	290,051

References

Aldrich, S.R. , W.O. Scott, and E.R. Leng, *Modern Crop Production*, A&L, 1978.

Committee on Beef Cattle Nutrition, *Nutrient Requirements of Beef Cattle*, National Academy Press, 1996.

Committee on Biobased Industrial Products, *Biobased Industrial Products: Priorities for Research and Commercialization*, National Research Council Report, Washington, DC, August 1999.

Bath, D., J. Dunbar, J. King, S. Berry and S. Olbrich, "Byproducts and Unusual Feedstuffs," *Feedstuffs*, 70(1998): 32-38.

Cross, T. and G. Perry, "Depreciation Patterns for Agricultural Machinery," *American Journal of Agricultural Economics* (Feb. 1995): 194-204.

Duffy, M., and D. Judd, *Estimated Costs of Crop Production in Iowa 1994*, FM1712, Ames, Iowa: Iowa State University Extension, Ames, IA , January 1994.

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

Gallagher, Paul, and Donald Johnson, "Some New Ethanol Technology: Cost Competition and Adoption Effects in the Petroleum Market. *The Energy Journal* 20(2):89-120. 1999.

Hayes, William A., "Estimating Wind Erosion in the Field," Proceedings of the Soil Conservation Society of America (Aug 1975):138:143, San Antonio, Texas

Hawkins, R., et al., *PLANETOR Users Manual*, St. Paul: Center for Farm Financial Management, University of Minnesota, 1995.

Hoag, D.L., and H.A. Holloway, "Farm Production Decisions under Cross and Conservation Compliance," *American Journal of Agricultural Economics*, (1991):184-193.

Jurgens, M.H., *Animal Feeding and Nutrition*, Kendall/Hunt Co. Dubuque, 1993.

Klingebiel, A. A., and P.H. Montgomery, "Land-Capability Classification," Agriculture Handbook No. 210, U.S. Department of Agriculture, Soil Conservation Service, 1961.

Khush, G., "Breaking the Yield Frontier in Rice," *Geojournal* (1993):331-3.

Larsen, J.B., "Firing Straw for the Production of Electricity with and without Producing District Heating," in R.P. Overend and E. Chornel, eds., *Making a Business From Biomass*, Proceedings of a Conference in Montreal, 1997, Pergamon Press.

Lazarus, W., *Minnesota Farm Machinery Economic Cost Estimates for 1997*, Minnesota Extension Service, St. Paul, 1997.

Lipinsky, E.S., T.A. McClure, J.L. Otis, D.A. Scantland, and W.J. Sheppard, *Systems Study of Fuels from Sugarcane, Sweet Sorghum, Sugar Beets and Corn*, Vol. IV "Corn Agriculture," Columbus, OH: Battelle Columbus Laboratories Report No. BMI-1957a (Vol. 4), March 1977.

Park, Y., *Costs of Producing Biomass Crops in Iowa*, Ph.D. Dissertation, Ames: Iowa State University, 1996.

Paturau, J.M., *By-Products of the Cane Sugar Industry*, Elsevier Co., Amsterdam, 1982.

Perry, G.M., B.A. McCarl, M.E. Rister, and J.W. Richardson, "Modeling Government Program Participation Decisions at the Farm Level," *American Journal of Agricultural Economics*(1989):1011-1020.

Plaster, E.J., *Soil Science & Management*, Delmar Co., Albany, 1992.

Reicosky, D.C., S.D. Evans, C.A. Cambardella, R. R. Allmaras, A.R. Wilts, and D.R. Huggins, "Continuous Corn with Moldboard Tillage: Silage and Fertility Effects on Soil Carbon," *Soil Science Social American Journal*, 2000.

Renard, K.G., G.R. Forster, D.K. McCool, G.A. Wessies, and D.C. Yoder. *RUSLE User's Guide*. Ankeny, IA: Soil and Water Conservation Society, 1993.

Russell, J.R., M. Brasche, and A.M. Cowen, "Effects of Grazing Allowance and System on the Use of Corn Crop Residues by Gestating Beef Cows," *Journal of American Science,* 71(1993):1256-5.

Shimojo, T., "Economic Analysis of Shipping Freights." Research Institute for Economics and Business Administration, Kobe University, 1979.

Skidmore, E.L., and N.P. Woodruff, *Wind Erosion Forces in the United States and Their Use in Predicting Soil Loss,* Agriculture Handbook No. 346, U.S. Department of Agriculture, April 1968.

Spelman, C.A., "Nonfood Uses of Agricultural Raw Materials: Economics," *Biotechnology and Politics*, CAB International, Wallingford, UK, 1994.

Stohbehn, D., and G.E. Ayres, *Pricing Machine-harvested Corn Residue*, Ames, IA: Cooperative Extension Service, Iowa State University, December 1976.

U.S. Department of Agriculture, Soil Conservation Service, KS, T.G. Notice KS-93, Dodge City, KS, June 1982.

U.S. Department of Agriculture, Soil Conservation Service, IA, *The Wind Erosion Equation*, Technical Guide, Section I-C-2, March 1987.

U.S. Department of Agriculture, Soil Conservation Service, *Conservation Catalog for the 1990's*, Des Moines, IA: October 1991.

U.S. Department of Agriculture Soil Survey Staff-Natural Resources Conservation Service, *National Soil Survey Handbook*, Title 430-VI, November 1996.

Wailes, E., "Farmer Survey of On-Farm Reservoir Investment Study," Department of Agricultural Economics, University of Arkansas, Fayetteville, AR, 1999.

Wischmeier, W.H., and Smith, D. D., *Predicting Rainfall Erosion Losses—A Guide to Conservation Planning,* Agriculture Handbook No. 537, U.S. Department of Agriculture, 1978.

Young, M. "Duck Gumbo," *Ducks Unlimited* February (1999):54-58.

Appendix tables A—Costs

Appendix table A-1—Story County, Iowa, corn stover harvest costs

Corn yield	(*bu/acre*)	147		
Gross stover yield	(*dw lb/acre*)	7694.153		
Conservation	(*dw lb/acre*)	1430	(*dwt/acre*)	0.715
Net stover yield	(*dw lb/acre*)	6264.153	(*dwt/acre*)	3.132077

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	0.951445 (*$/ton*)	3.31 (*$/acre*)	1.056807	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.005723 (*$/ton*)	6.49 (*$/acre*)	2.072108		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		2.467168 (*$/ton*)		3.798915	6.266083	5.086083

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.916062		
K2o	$0.01	152	0.60	253.3333	3.097507		(*$/ton*)
NH3	0.008093	303	1.00	303	2.452179	6.465748	7.645748
					Total direct & fertilizer(*$/ton s*)	12.73183	12.73183

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-2—Riley County, Kansas, continuous winter wheat, straw harvest costs

Wheat yield	(*bu/acre*)	40.7		
Gross straw yield	(*dw lb/acre*)	4070		
Conservation	(*dw lb/acre*)	715	(*dwt/acre*)	0.3575
Net straw yield	(*dw lb/acre*)	3355	(*dwt/acre*)	1.6775

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.776453 (*$/ton*)	3.31 (*$/acre*)	1.973174	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.877794 (*$/ton*)	6.49 (*$/acre*)	3.868852		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		4.16424 (*$/ton*)		6.512027	10.67627	9.496274

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.458031		
K2o	$0.01	152	0.60	253.3333	3.033413		(*$/ton*)
NH3	0.004938	303	1.00	303	1.496214	4.987658	6.167658
					Total direct & fertilizer(*$/ton s*)	15.66393	15.66393

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-3—Riley County, Kansas, sorghum stover harvest costs

Sorghum yield	(*bu/acre*)	80.9		
Gross stover yield	(*dw lb/acre*)	4854		
Conservation	(*dw lb/acre*)	1500	(*dwt/acre*)	0.75
Net stover yield	(*dw lb/acre*)	3354	(*dwt/acre*)	1.677

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.776983 (*$/ton*)	3.31 (*$/acre*)	1.973763	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.878354 (*$/ton*)	6.49 (*$/acre*)	3.870006		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		4.165337 (*$/ton*)		6.513769	10.67911	9.499106

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	1.190767		
K2o	$0.01	152	0.60	253.3333	2.56348		(*$/ton*)
NH3	0.007133	303	1.00	303	2.161299	5.915546	7.095546
					Total direct & fertilizer(*$/ton s*)	16.59465	16.59465

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-4—Ford County, Kansas, wheat/fallow, straw harvest costs

Wheat yield	(*bu/acre*)	28.491		
Gross straw yield	(*dw lb/acre*)	2849.1		
Conservation	(*dw lb/acre*)	1500	(*dwt/acre*)	0.75
Net straw yield	(*dw lb/acre*)	1349.1	(*dwt/acre*)	0.67455

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	4.41776 (*$/ton*)	3.31 (*$/acre*)	4.906975	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	4.66978 (*$/ton*)	6.49 (*$/acre*)	9.621229		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		9.59754 (*$/ton*)		15.1982	24.79574	23.61574

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.458031		
K2o	$0.01	152	0.60	253.3333	3.033413		(*$/ton*)
NH3	0.004938	303	1.00	303	1.496214	4.987658	6.167658
					Total direct & fertilizer(*$/ton s*)	29.7834	29.7834

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-5—Ford County, Kansas, sorghum stover harvest costs

Sorghum yield	(*bu/acre*)	80.2		
Gross stover yield	(*dw lb/acre*)	4812		
Conservation	(*dw lb/acre*)	1500	(*dwt/acre*)	0.75
Net stover yield	(*dw lb/acre*)	3312	(*dwt/acre*)	1.656

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.799517 (*$/ton*)	3.31 (*$/acre*)	1.998792	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.902174 (*$/ton*)	6.49 (*$/acre*)	3.919082		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		4.211691 (*$/ton*)		6.587874	10.79957	9.619565

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	1.190767		
K2o	$0.01	152	0.60	253.3333	2.56348		(*$/ton*)
NH3	0.007133	303	1.00	303	2.161299	5.915546	7.095546
					Total direct & fertilizer(*$/ton s*)	16.71511	16.71511

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-6—Ford County, Kansas corn stover harvest costs

Corn yield	(*bu/acre*)	173.1		
Gross stover yield	(*dw lb/acre*)	9060.258		
Conservation	(*dw lb/acre*)	2400	(*dwt/acre*)	1.2
Net stover yield	(*dw lb/acre*)	6660.258	(*dwt/acre*)	3.330129

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	0.89486 (*$/ton*)	3.31 (*$/acre*)	0.993956	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	0.945909 (*$/ton*)	6.49 (*$/acre*)	1.948873		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		2.35077 (*$/ton*)		3.612829	5.963599	4.783599

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
O2o5	$0.00	257	0.45	571.1111	0.916062		
K2o	$0.01	152	0.60	253.3333	3.097507		(*$/ton*)
NH3	0.008093	303	1.00	303	2.452179	6.465748	7.645748
					Total direct & fertilizer(*$/ton s*)	12.42935	12.42935

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-7—Norman County, Minnesota, spring wheat, straw harvest costs

Wheat yield	(*bu/acre*)	31.193		
Gross straw yield	(*dw lb/acre*)	3119.3		
Conservation	(*dw lb/acre*)	715	(*dwt/acre*)	0.3575
Net straw yield	(*dw lb/acre*)	2404.3	(*dwt/acre*)	1.20215

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	2.478892 (*$/ton*)	3.31 (*$/acre*)	2.7534	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	2.620305 (*$/ton*)	6.49 (*$/acre*)	5.398661		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		5.609197 (*$/ton*)		8.822061	14.43126	13.25126

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.458031		
K2o	$0.01	152	0.60	253.3333	3.033413		(*$/ton*)
NH3	0.004938	303	1.00	303	1.496214	4.987658	6.167658
					Total direct & fertilizer(*$/ton s*)	19.41892	19.41892

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-8—Norman County, Minnesota, barley straw harvest costs

Barley yield	(*bu/acre*)	54.9		
Gross straw yield	(*dw lb/acre*)	4392		
Conservation	(*dw lb/acre*)	715	(*dwt/acre*)	0.3575
Net straw yield	(*dw lb/acre*)	3677	(*dwt/acre*)	1.8385

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.620887 (*$/ton*)	3.31 (*$/acre*)	1.800381	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.713353 (*$/ton*)	6.49 (*$/acre*)	3.530052		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		3.84424 (*$/ton*)		6.000432	9.844672	8.664672

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.641358		
K2o	$0.02	152	0.60	253.3333	5.062613		(*$/ton*)
NH3	0.005898	303	1.00	303	1.787094	7.491065	8.671065
					Total direct & fertilizer(*$/ton s*)	17.33574	17.33574

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-9—Norman County, Minnesota, oat straw harvest costs

Oat yield	(*bu/acre*)	67.7		
Gross straw yield	(*dw lb/acre*)	4062		
Conservation	(*dw lb/acre*)	715	(*dwt/acre*)	0.3575
Net straw yield	(*dw lb/acre*)	3347	(*dwt/acre*)	1.6735

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.780699 (*$/ton*)	3.31 (*$/acre*)	1.977891	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.882283 (*$/ton*)	6.49 (*$/acre*)	3.8781		15.93
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		4.172982 (*$/ton*)		6.52599	10.69897	9.518972

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	$0.00	257	0.45	571.1111	0.549409		
K2o	$0.02	152	0.60	253.3333	5.489733		(*$/ton*)
NH3	0.0060036	303	1.00	303	1.819091	7.858233	9.038233
					Total direct & fertilizer(*$/ton s*)	18.55721	18.55721

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix table A-10—Arkansas County, Arkansas, rice straw harvest costs

		0.845		
Rice yield	(*lb/acre*)	6200		
Gross straw yield	(*dw lb/acre*)	5239		
Conservation	(*dw lb/acre*)	0	(*dwt/acre*)	0
Net straw yield	(*dw lb/acre*)	5239	(*dwt/acre*)	2.6195

Direct harvest costs

Operation	Fixed costs		Variable costs		Total costs	
	Reported	Per ton s	Reported	Per ton s		
Chop	2.98 (*$/acre*)	1.137622 (*$/ton*)	3.31 (*$/acre*)	1.2636	(*$/ton s*)	(*$/ac*)
Bale	3.15 (*$/acre*)	1.20252 (*$/ton*)	6.49 (*$/acre*)	2.477572		35.93
Hunting lease	20 (*$/acre*)	7.635045				
Haul		0.51 (*$/ton*)		0.67		(*$/ton*)
		10.48519 (*$/ton*)		4.411172	14.89636	13.71636

Fertilizer replacement costs

	Fertilizer application rates gross	Fertilizer price			Fertilizer expense		
		Dilute	Strength	Pure			
	(*t f/ dwt s*)	(*$/ton f*)		(*$/ton f*)	(*$/ton s*)		
P2o5	0.00128	257	0.45	571.1111	0.732736		
P2o	0.01113	152	0.60	253.3333	2.8196		(*$/ton*)
NH3	0.006713	303	1.00	303	1.870419	5.422755	6.602755
					Total direct & fertilizer(*$/ton s*)	20.31911	20.31911

Note: dw = dry weight. $/ton f = dollars per ton of fertilizer. $/ton s = dollars per ton of stover or straw. tf = tons fertilizer.

Appendix tables B—Quantity

Appendix table B-1—Corn Belt, corn stover supply and use

State	IL	IN	IA	KS	KY	MN	MO	NE	OH	SD	WI	Total
Corn yield (*bu/acre*)	139	129	137	134		118	117	126	125	90	104	
Corn stover yield (*lb/acre*)	5,613	5,063	5,489	5,323		4,549	4,505	4,956	4,883	3,124	3,826	
Corn area:												
Erodible fraction (0/1)	0.167	0.1705	0.3256	0.2449	0.4174	0.1534	0.4391	0.4674	0.4739	0.2926	0.2737	
Harvested for stover (*mil. acre*)	9.3296	5.05995	8.90208	1.396935	0.827292	6.09552	1.40225	4.42058	1.99918	2.68812	2.83179	44.9533
Corn stover production (*mil. lb*)	52,370.5	2,5249.8	44,741.2	9,105.7		27,413.1	7,403.2	22,930.8	13,495.7	8,295.3	10,667.66	207,198.5
Net corn stover forage demand (*mil. lb*)	0	0	2,711.0	4,736.3		0	5,047.2	7,563.0	0	1,123.9	2,606.8	23,786
Net corn stover supply for industrial processing (*mil. lb*)	52,370.5	25,249.8	42,030.2	4,369.4		27,413.1	2,355.9	15,367.7	13,495.7	7,171.3	8,060.8	197,884.4

Appendix table B-2—Great Plains: Residue supply for industrial processing

State	CO	KS	MN	MT	NE	ND	OK	SD	Total
					Million lbs				
Total residue production	2,130	24,518	5,471	7,622	3,447	30,464	2,825	4,563	81,040
Net residue forage demand	907	5,085	0	725	1,348	121	1,651	157	9,994
Net residue supply for industrial processing	1,223	19,433	5,470	6,896	2,098	30,343	1,174	4,405	71,042

Appendix table B-3—Production and use of Great Plains residues, by crop and State, 1997 baseline

State	Crop	Residue yield	Erodible	Non-erodible	Production	Livestock use	Industrial use
		Lbs/acre	*Fraction*	*Mil. acres*	*Mil. lbs*	*Mil. lbs*	*Mil. lbs*
CO	Barley	2,913	0.43	.003	7.9	1.2	6.7
	Corn	4,186	0.72	.248	1,038.1	506.6	531.6
	Oats	0	1.00	0	0	0	0
	S Wheat	0	1.00	0	0	0	0
	Sorghum	1,054	0.70	.043	45.5	18.4	27.1
	W Wheat (Cont)	2,235	0.60	.062	139.7	87.8	51.8
	W Wheat (Fallow)	1,553	0.74	.579	899.4	293.3	606.1
KS	Barley	0	1.00	0	0	0	0
	Corn	6,341	0.58	1.025	6,500.1	2,402.7	4,097.4
	Oats	0	1.00	0	0	0	0
	S Wheat	0	1.00	0	0	0	0
	Sorghum	2,923	0.64	1.129	3,299.4	1,592.7	1,706.7
	W Wheat (Cont)	2,965	0.38	3.537	10,487.5	690.1	9,797.3
	W Wheat (Fallow)	1,996	0.57	2.120	4,231.5	399.7	3,831.8
MN	Barley	4,076	0.39	.239	975.2	0	975.2
	Corn	2,691	0.63	.234	629.1	0	629.1
	Oats	2,870	0.39	.051	146.8	0	146.8
	S Wheat	2,740	0.37	1.354	3,708.9	0	3,709.0
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	2,871	0.91	.004	10.5	0	10.5
	W Wheat (Fallow)	0	1.00	0	0	0	0
MT	Barley	3,532	0.41	.430	1,517.8	534.5	983.3
	Corn	0	1.00	0	0	0	0
	Oats	2,557	0.38	.016	41.8	38.1	3.7
	S Wheat	2,670	0.37	2.206	5,890.6	152.5	5,738.1
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	3,309	0.93	.007	24.1	0	24.1
	W Wheat (Fallow)	2,504	0.92	.058	147.3	0	147.3
NE	Barley	0	1.00	0	0	0	0
	Corn	4,789	0.74	.408	1,953.9	843.3	1,110.6
	Oats	2,490	0.87	.002	4.9	0	4.9
	S Wheat	0	1.00	0	0	0	0
	Sorghum	3,566	0.66	.120	427.2	183.3	244.0
	W Wheat (Cont)	3,046	0.53	.110	335.4	100.6	234.9
	W Wheat (Fallow)	2,133	0.72	.340	725.2	221.3	503.9
ND	Barley	3,804	0.14	1.941	7,386.0	47.5	7,338.5
	Corn	2,717	0.84	.123	333.9	14.2	319.7
	Oats	2,922	0.26	.306	894.8	47.9	847.0
	S Wheat	2,492	0.20	8.768	21,847.9	11.5	21,836.4
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	2,245	0.97	0	1.6	0	1.6
	W Wheat (Fallow)	1,460	0.99	0	.4	0	.4

Continued--

Appendix table B-3—Production and use of Great Plains residues, by crop and State, 1997 baseline--continued

State	Crop	Residue yield	Erodible	Non-erodible	Production	Livestock use	Industrial use
		Lbs/acre	*Fraction*	*Mil acres*	*Mil lbs*	*Mil. lbs*	*Mil. lbs*
OK	Barley	4,018	0.56	.000	1.7	0	1.6
	Corn	5,688	0.86	.018	107.5	107.5	0
	Oats	1,351	0.82	.005	6.6	5.6	1.1
	S Wheat	0	1.00	0	0	0	0
	Sorghum	1,795	0.78	.084	151.2	110.6	40.7
	W Wheat (Cont)	1,777	0.69	1.402	2,491.5	1,361.1	1,130.4
	W Wheat (Fallow)	1,303	0.78	.052	67.3	66.7	.6
SD	Barley	3,268	0.45	.038	123.9	0	123.9
	Corn	1,753	0.75	.362	634.3	74.3	560.0
	Oats	3,007	0.29	.084	252.4	22.7	229.8
	S Wheat	2,579	0.39	1.012	2,610.1	59.1	2,551.0
	Sorghum	1,589	0.62	.004	6.4	1.9	4.5
	W Wheat (Cont)	3,093	0.40	.179	554.5	0	554.5
	W Wheat (Fallow)	2,274	0.56	.168	381.9	0	381.9
Totals				28.871	81,044.0	9,996.7	70,726.0

Appendix table B-4—West Coast: Residue supply for industrial processing

State	CA	OR	WA	Total
			Million lbs	
Total residue production	1,601.7	1,856.2	3,919.3	7,377.2
Net residue forage demand	1,467.8	641.2	463.7	2,572.7
Net residue supply for industrial processing	133.9	1,215.0	3,455.7	4,804.6

Appendix table B-5—Production and use of West Coast residues, by crop and State, 1997 baseline

State	Crop	Residue yield	Erodible	Non-erodible	Production	Livestock	Industrial
		Lbs/acre	*Fraction*	*Mil. acres*	*Mil. lbs*	*Mil. lbs*	*Mil. lbs*
CA	Barley	4,686	0.43	.085	398.1	395.1	2.0
	Corn	2,161	0.08	.535	1,156.2	1,024.3	131.9
	Oats	5,910	0.91	.003	16.1	16.1	0
	S Wheat	0	1.00	0	0	0	0
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	6,197	0.99	.005	30.0	30.0	0
	W Wheat (Fallow)	5,527	0.99	0	2.4	2.4	0
OR	Barley	4,684	0.28	.084	391.3	161.1	230.2
	Corn	2,229	0.66	.016	35.6	33.2	2.4
	Oats	5,441	0.77	.007	39.3	24.3	15.0
	S Wheat	4,146	0.36	.077	319.7	73.9	245.8
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	7,647	0.64	.109	835.0	296.8	538.1
	W Wheat (Fallow)	4,823	0.90	.049	235.4	51.9	183.6
WA	Barley	4,320	0.67	.159	684.8	160.8	524.1
	Corn	6,12	0.69	.043	284.0	54.1	229.9
	Oats	3,892	0.30	.009	31.2	13.7	17.4
	S Wheat	4,143	0.48	.219	906.9	133.8	773.0
	Sorghum	0	1.00	0	0	0	0
	W Wheat (Cont)	5,924	0.76	.156	925.6	73.7	851.9
	W Wheat (Fallow)	4,557	0.84	.238	1,086.8	27.5	1,059.3
Totals:				1.794	7,378.4	2,806.1	4,804.6

Appendix table B-6—Delta: Rice straw supply and use

State	AR	LA	MS	MO	TX	Total
Rice yield (*lb/acre*)	5.700	4.837	5.774	5.385	5.465	
Residue yield (*lb/acre*)	4.816	4.087	4.879	4.550	4.618	
Harvested acres (*mil. acre*)	1.328	.493	.224	.112	.075	2.232
Residue production (*mil. lbs*)	6,472.3	1,985.8	1,102.2	505.1	369.9	10,435.3
Net residue forage demand (*mil. lbs*)	439	436	52	53	207	1,168.0
Industrial supply (*mil. lbs*)	6,033.3	1,549.8	1,050.2	452.1	162.0	9,246.3

Appendix table B-7—Southeast: Sugarcane bagasse supply and use*

State	FL	HA	LA	TX	Total
Sugarcane yield (*ton/acre*)	35.36	81.88	26.64	30.77	
Bagasse yield (*tons/acre*)	8.84	20.47	6.66	7.69	
Harvested acres (*mil. acre*)	.421	.032	.379	.027	0.859
Residue production (*mil. ton*)	3,721.9	655.0	2,527.1	210.0	7,114.0

*mill run (49% moisture) basis

Glossary

Crop residue: Plant matter remaining after removing the food or feed component.

Fallow/plant: The process of leaving land unseeded during one growing season, for purposes of water accumulation in semi-arid climates, and planting in a subsequent growing season.

Stover yield: The corn (or sorghum) residue produced per acre of land planted to corn (or sorghum).

Harvest costs: For crop residues, the costs of collecting, chopping, baling, and moving residues to a central place on the farm. Fertilizer replacement is also included.

Forage: Feed for livestock, often consisting of coarsely chopped corn residues, hay, straw and other planted material with high cellulose content.

Tillage: Cultivation of land.

No-till system: A crop production system that does not use a conventional plow to break-up the soil. Often, a drill is used to plant seeds.

Transport costs: Fuel, maintenance, and capital costs associated with using a truck or tractor to move biomass from the farm to the processing plant.

Biomass: Plant matters grown to produce non-food products, such as liquid fuel or electricity.