Reprinted from the *Journal of Environmental Quality*
Vol. 8, no. 4, October–December 1979, Copyright © 1979, ASA, CSSA, SSSA
677 South Segoe Road, Madison, WI 53711 USA

Soil Conservation Limitations on Removal of Crop Residues for Energy Production

M. J. LINDSTROM, E. L. SKIDMORE, S. C. GUPTA, AND C. A. ONSTAD

Soil Conservation Limitations on Removal of Crop Residues for Energy Production[1]

M. J. LINDSTROM, E. L. SKIDMORE, S. C. GUPTA, AND C. A. ONSTAD[2]

ABSTRACT

Potential soil erosion by water for Major Land Resource Areas (MLRA) in the Corn Belt and by wind in the Great Plains was calculated using the Universal Soil Loss Equation and the Wind Erosion Equation for current cropping practices. Crop statistics and components of the erosion equations were obtained from the States Crop Reporting Service, Soil Conservation Service, and information available from related literature. The calculations showed that only limited quantites of residue can safely be removed from either region because of soil erosion potentials. In the Corn Belt under conventional tillage with all residues removed only 36% of the cultivated area would have a soil loss at less than the soil loss tolerance (T) level. Residue and tillage management can increase the area adequately protected to 78%. In the Great Plains only 40 and 56% of the cultivated area produce enough residue to hold soil loss by wind at 6.7 and 11.2 metric tons/ha per year, respectively, when the fields are wide and the soil surface is smooth, i.e., K = 1.0. Increasing soil surface roughness, K = 0.5, increases the cultivated area to 81% where enough residue is produced to maintain a soil loss level of 11.2 metric tons/ha per year.

Additional Index Words: **water erosion, wind erosion, residue management, crop residues.**

Reports by Alich and Inman (2) and Steffgen (14) showed that high amounts of potential energy are contained in crop residue. However, crop residue should not be considered as a waste product as these reports implied. Crop residues influence soil properties, both physically and chemically, primarily as either stable or unstable soil organic matter, which is important in maintaining long-term soil productivity.

Crop residues are also an effective soil-erosion-control device for both wind and water erosion. Adams (1), Kramer and Meyer (8), Mannering and Meyer (9), Meyer et al. (10), and others have reported that surface residues reduce soil loss by water erosion primarily by intercepting raindrop impact and by reducing the velocity of runoff water. Chepil (4), Chepil et al. (5, 6), Englehorn et al. (7), and Siddoway et al. (12) have reported that residues reduce wind erosion by reducing wind speed and by preventing direct wind force from reaching erodible soil particles. Both the Universal Soil Loss Equation (USLE) of Wischmeier and Smith (17) for water erosion and the Wind Erosion Equation (WEE) of Woodruff and Siddoway (18) include components that estimate the effects of residue on the soil-erosion process.

Although crop residues are often not managed to provide maximum soil erosion protection, removal of residues would increase the present level of soil erosion. Wischmeier (16) reported that each 2.2 metric tons/ha (1 ton/acre) of buried residue reduces soil erosion by water 12% as compared with removing all residue.

[1] Contribution from the North Central Soil Conserv. Res. Lab., USDA-SEA, AR, Morris, Minn., in cooperation with the Minnesota Agric. Exp. Stn., Sci. Jour. Series no. 10,429. Received 21 Dec. 1978.

[2] Soil Scientists, USDA-SEA, AR, Morris, Minn., Manhattan, Kansas, and St. Paul, Minn.; and Agricultural Engineer, USDA-SEA, AR, Morris, Minn., respectively.

In this paper, we will estimate the amounts of residue that can be safely removed in the Corn Belt and in the Great Plains. We will use predicted soil erosion, as calculated from the USLE (17) and the WEE (18), to determine the amounts of residue required on the soil for water erosion control in the Corn Belt and for wind erosion control in the Great Plains, respectively. The only restraints placed on residue removal for this determination will be soil erosion and we make no attempts at predicting long-term effects on soil productivity associated with residue removal.

ESTIMATION PROCEDURE

The study area includes four Land Resource Regions (3) as shown in Fig. 1. These include Major Land Resource Areas (MLRA) 52 to 80 in the Great Plains and 102 to 115 in the Corn Belt.

The USLE (17) was used to calculate soil loss by water erosion in the Corn Belt. The equation form is:

$$A = RKLSCP \qquad [1]$$

where A = computed soil loss, R = rainfall factor, K = soil erodibility factor, L = slope length factor, S = slope gradient factor, C = cropping management factor, and P = erosion control practice factor. Components of the equation were obtained from the following sources: R from published values (17); K from the Soil Survey Laboratory, Soil Conservation Service (SCS), Lincoln, Nebr.; L from the respective SCS State offices (as an average slope length for each slope gradient class); S from soil survey data contained in the Conservation Needs Inventory (15); and C from respective SCS State offices for tillage and rotation systems. P was assumed equal to 1.0 which corresponds to straight up and down slope tillage with no conservation practices.

In determining the C values it was necessary to assign crop rotations to the soil series and slope gradient classifications based on crop production values within the study units obtained from the respective State Crop Reporting Service. Row crops (corn and soybeans) were assigned to the less erosive gentle slopes, and small grains and hay to steeper slopes with the amounts of crop assigned within the study units agreeing within 1 percentage point with the Crop Reporting Service data. The study units were MLRA within states. For example, MLRA 102 is located in four states; South dakota, Minnesota, Iowa, and Nebraska. A separate analysis was made for MLRA 102 in each state. The results, however, are reported on a MLRA basis.

Soil erosion estimates were made for five tillage and residue systems:

A1 = conventional tillage (all residue removed),
A2 = conservation tillage (1.68 metric tons/ha residue remaining),
A3 = conservation tillage (3.9 metric tons/ha residue remaining),
A4 = no till (1.68 metric tons/ha residue remaining),
A5 = no till (3.9 metric tons/ha residue remaining).

Small grain and soybean residues were assumed to be twice as effective as corn residue on a weight basis because of the greater surface area covered by small grain and soybean residue for equal weights. Therefore, in systems A2 and A4, and A3 and A5, 0.84 and 1.96 metric tons/ha, respectively, of residue remained on the soil surface for these crops in the rotation. The conventional tillage was considered to be a fall plow, spring disk, and harrow. The conservation tillage systems were considered to be equivalent to a subsurface tillage system with 66% surface coverage. The no till systems had 90% surface coverage. Calculations were made on an individual soil series and slope gradient classification. Results were then compared with the assigned T value to determine if residue could be removed. T values are defined by the SCS as the maximum soil loss that is considered safe for continued long-term maximum productivity of the soil.

A computer solution (13) of the WEE (18) was used to calculate soil

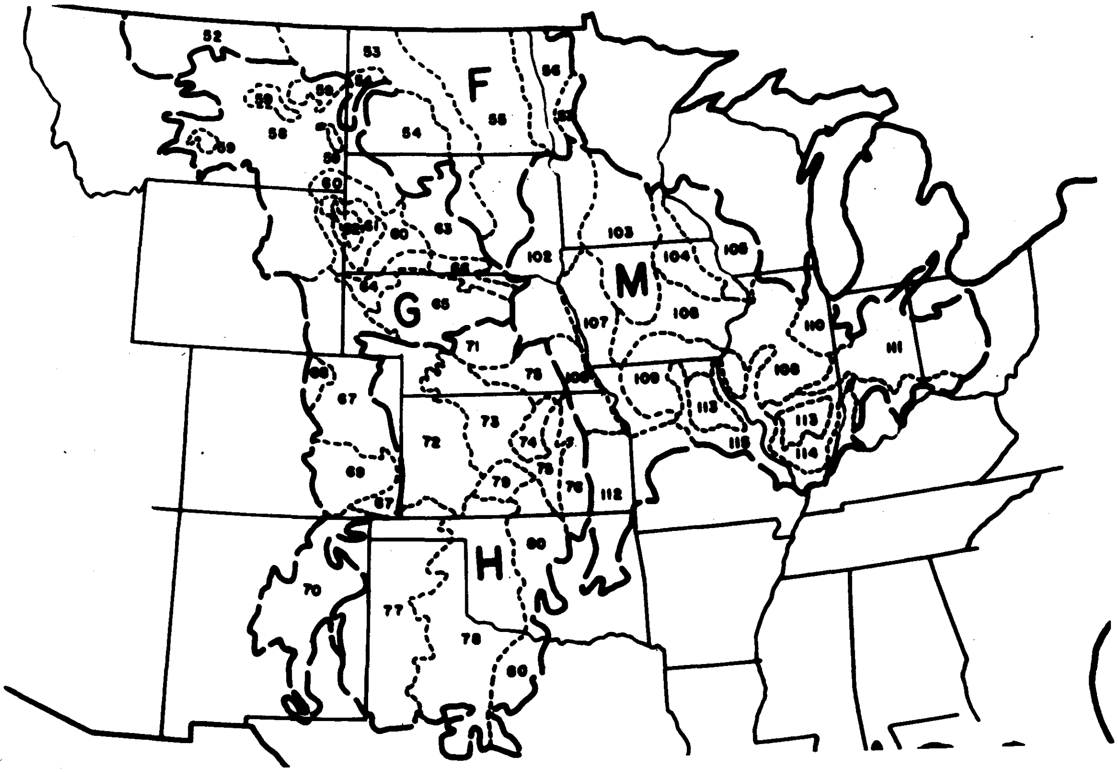

Fig. 1—Land Resource Regions: F, Northern Great Plains Spring Wheat Region; G, Western Great Plains Range and Irrigated Region; H, Central Great Plains Winter Wheat and Range Region; and M, the Central Feed Grains and Livestock Region (3) with Major Land Resource Areas 52-80 in the Great Plains (F, G, and H) and 102-115 in the Corn Belt (M).

loss by wind erosion in the Great Plains region. The equation form is:

$$E = f(I, K, C, L, V), \qquad [2]$$

where E = computed soil loss, I = soil erodibility factor, K = ridge roughness factor, C = climatic factor, L = field length, and V = equivalent quantity of vegetative cover. Components of the equation were determined as: I, the weighted aveage for each MLRA, based on soil textural classification and hectarage, as given by the Conservation Needs Inventory (15); C, the average value for each MLRA calculated from the county average climatic factor (18) for counties within the respective MLRA; L was assumed wide, meaning that an increase in L would not increase the erosion hazard. This condition usually occurs for a field width of 500 to 1,000 m. The WEE was solved for equivalent vegetative cover, V, for the following E and K conditions:

1) E = 6.7 metric tons/ha per year, K = 1.0
2) E = 11.2 metric tons/ha per year, K = 1.0
3) E = 11.2 metric tons/ha per year, K = 0.5
4) E = 22.4 metric tons/ha per year, K = 0.5.

The values of soil roughness, K, correspond to a smooth (1.0) and a rough (0.5) surface condition. The equivalent vegetative cover was converted to flat, small-grain residue for wheat, barley, and oats and to standing stubble 30 cm high for corn and sorghum.

The equivalent vegetative cover is based on the amounts of residue in a protective position during the season when wind erosion is a hazard. However, the amounts of residue that remain effective for wind-erosion control decrease with tillage operations and weathering. Based on our experiences and data from the literature, the effective amounts of residue were calculated from the following ratios:

Crop	*Residue remaining ratio*
Continuous wheat	0.75
Fallow wheat	0.50
Barley	0.60
Oats	0.60
Corn	0.80
Sorghum	0.80

Estimations of the amounts of residue produced that were greater than that needed for wind-erosion control for the specified conditions were made from using the following equation:

$$SR = RP - (RN/RR) \qquad [3]$$

where SR = surplus residue, RP = residue production, RN = residue needed for control, and RR = residue remaining ratio.

Quantities of residue produced for the Corn Belt and Great Plains were calculated by multiplying a factor of straw to grain ratio. Factors used were:

Crop	*Ratio*
Corn	1:1
Sorghum	1:1
Soybeans	1.5:1
Spring wheat	1.3:1
Winter wheat	1.7:1
Durum wheat	1.0:1
Oats	2:1
Barley	1.5:1

All small grains were converted to an equivalent oat basis in the Corn Belt and residue yields were determined using the straw/grain ratio for oats. Grain yields were obtained from the State Crop Reporting Service and are an average of 3 years (1973 to 1975) data for the Great Plains and 5 years (1972 to 1976) data for the Corn Belt.

RESULTS AND DISCUSSION

The harvested area and residue production by crops for the MLRA's in the Corn Belt and Great Plains are shown in Tables 1 and 2. We have assumed that residue could only be considered available for removal if the predicted soil loss from the USLE in the Corn Belt or

Table 1—Number of hectares harvested and residue production per hectare for the major crops in the Corn Belt.

MLRA	Corn		Soybeans		Small grain	
	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha
102	1,933	3.7	580	2.5	1,141	4.2
103	2,608	5.5	1,795	3.2	373	4.5
104	751	5.5	482	2.8	149	4.7
105	728	5.6	154	2.6	239	5.1
106	663	4.0	194	2.6	214	4.1
107	1,440	4.9	789	3.1	201	5.8
108	3,099	6.6	1,929	3.4	366	5.1
109	489	4.1	477	2.4	109	3.8
110	603	6.4	511	3.2	59	5.3
111	2,003	5.8	1,691	3.0	671	5.0
112	534	3.6	458	2.1	274	3.7
113	351	4.3	515	2.4	187	3.8
114	555	5.7	612	2.8	226	4.0
115	818	5.5	685	2.9	319	3.9
Total	16,575		10,872		4,528	

Table 3—Residue availability by crops for conventional tillage system, A1.

MLRA	Corn	Soybeans	Small grain
	metric tons × 10⁶		
102	4.0	1.0	2.3
103	9.0	4.5	0.4
104	2.1	0.9	0.2
105	1.1	0.1	0.3
106	0.3	0.1	0.1
107	1.4	0.7	–
108	5.6	2.7	0.1
109	0.1	0.1	–
110	1.8	0.8	0.1
111	4.6	2.3	0.3
112	0.4	0.1	0.3
113	–†	–	–
114	0.2	0.1	0.1
115	0.3	0.2	0.1
Total	30.9	13.6	4.3

† <0.1 million metric tons.

the WEE in the Great Plains was less than or equal to the T value. T values were obtained for soil series from the Soil Survey Laboratory, Lincoln, Nebr., for the Corn Belt. For the Great Plains, a uniform T value was imposed in the Wind Erosion Equation as the E value.

Using this criterion, the amounts of residue that would be available for removal from the major crops in the Corn Belt under conventional tillage, system A1, is shown in Table 3. The amount of residue that is available for removal under this tillage system is about 49 million metric tons or 36% of the total residue produced. Available corn residue accounted for over 65% of this amount.

Residue availability in the Great Plains under an imposed soil loss level of 11.2 metric tons/ha per year and a surface roughness of 1.0, condition 2, is shown in Table 4. For this situation, about 16 million metric tons or 21% of the total residue produced could be removed. Available wheat and corn residue accounted for about 85% of this amount.

The amounts of residue available for removal and percent area adequately protected against water erosion in the Corn Belt for the five tillage and residue systems is shown in Table 5. In calculating the amounts of residue available for removal, we assumed that, when residue became available for removal in a tillage system,

Table 2—Number of hectares harvested and residue production per hectare for the major crops in the Great Plains.

MLRA	Wheat		Barley		Oats		Corn		Sorghum	
	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha	ha × 10³	metric tons/ha
52	804	2.8	245	2.4	25	2.5	–†	3.0	–‡	
53	1,478	1.8	138	2.4	224	2.5	44	1.7	4	1.5
54	510	1.9	67	2.7	127	2.6	2	1.9	–†	1.1
55	2,025	1.9	563	2.5	456	2.7	235	2.0	18	2.0
56	1,151	2.7	464	3.3	239	3.1	82	3.5	–‡	
57	66	2.4	39	3.0	91	3.0	32	3.3	–‡	
58	160	3.2	60	2.9	18	2.9	3	4.5	–‡	
59	242	2.8	55	3.1	26	3.1	1	4.1	–‡	
60	25	2.9	5	2.0	16	2.6	4	4.8	–†	1.5
61	30	3.6	2	1.8	6	2.1	1	2.9	–†	1.2
62	1	2.9	–†	1.9	1	2.4	–†	3.0	–†	1.2
63	156	3.0	6	1.7	39	2.3	5	2.4	19	1.6
64	49	3.3	3	2.4	8	2.3	7	4.7	1	1.4
65	17	3.5	2	2.8	10	2.4	99	5.9	2	2.2
66	31	3.2	7	2.1	36	2.8	33	2.1	15	1.9
67	747	2.8	28	2.8	13	2.4	114	5.9	46	1.5
68	75	2.6	–‡		–‡		29	6.5	–†	2.3
69	147	2.4	4	3.4	1	2.6	14	6.0	43	2.4
70	30	2.0	1	2.7	–‡		5	4.9	15	1.6
71	58	4.1	1	2.6	6	2.7	318	6.0	24	2.6
72	1,729	3.6	6	2.7	5	2.4	465	6.4	205	3.2
73	870	3.6	2	2.8	7	2.8	145	6.3	285	2.7
74	302	3.6	1	3.0	5	2.5	15	4.4	113	2.9
75	716	3.8	2	3.1	23	3.1	568	6.5	602	3.3
76	200	3.5	4	3.2	12	2.5	29	3.5	191	2.9
77	1,145	2.8	12	3.6	4	2.5	281	7.4	1,287	3.8
78	1,196	2.7	30	2.1	66	2.3	1	57	298	2.3
79	439	3.3	2	29	1	2.4	19	6.7	90	2.7
80	1,198	3.4	37	2.6	36	2.6	4	5.1	77	2.6
Total	15,597		1,789		1,252		2,410		3,355	

† <1,000 ha harvested in MLRA.
‡ No reported harvested area in MLRA.

Table 4—Residue availability by crops for soil loss level of 11.2 metric tons/ha and a surface roughness of 1.0.

MLRA	Wheat		Barley		Oats		Corn		Sorghum	
	metric tons/ha	metric tons × 10³	metric tons/ha	metric tons × 10³	metric tons/ha	metric tons × 10³	metric tons/ha	metric tons × 10³	metric tons/ha	metric tons × 10³
52	−0.4†		−0.6		−0.5		−1.2		–¶	
53	−0.8		0.1	14	0.1	22	−1.8		−2.1	
54	−0.6		0.5	34	0.4	51	−1.5		−2.3	
55	−0.3		0.4	225	0.6	274	−1.3		−1.2	
56	0.9	1,036	1.3	603	1.2	287	0.4	33	–¶	
57	1.7	112	2.2	86	2.2	200	1.9	61	–¶	
58	0.7	112	0.6	36	0.6	11	1.0	3	–¶	
59	−0.1		0.3	17	0.3	8	0.2	–‡	–¶	
60	0.4	10	−0.2		0.3	5	1.4	6	−2.0	
61	1.2	36	−0.3		–‡	–§	−0.5		−2.1	
62	0.5	–§	−0.3		0.2	–§	−0.4		−2.2	
63	0.5	78	−0.5		–‡	–§	−1.1		−1.8	
64	0.8	14	0.2	1	0.1	1	1.3	9	−2.0	
65	0.6	19	0.2	–§	−0.2		2.3	228	−1.4	
66	1.0	31	–‡	–§	0.7	25	−1.2		−1.3	
67	−0.3		–‡	–§	−0.4		2.0	228	−2.4	
68	−0.5		–¶		–¶		2.6	75	−1.7	
69	−0.8		0.5	2	−0.3		1.9	27	−1.6	
70	−1.0		−0.7		–¶		–‡	–§	−3.3	
71	1.8	104	0.4	–§	0.6	4	2.8	890	−0.6	
72	–‡	–§	−0.4		−0.7		2.1	977	−1.2	
73	1.0	870	0.3	1	0.3	2	2.6	377	−1.0	
74	1.9	574	1.0	1	0.6	3	1.3	20	−0.1	
75	2.2	1,575	1.3	3	1.3	30	3.5	1,988	0.3	181
76	2.2	440	1.6	6	1.0	12	0.9	26	0.4	76
77	−0.9		0.4	5	−0.7		2.8	787	−0.7	
78	–‡	–§	−0.5		−0.3		2.0	2	−1.5	
79	0.8	351	0.3	1	−0.2		2.8	53	−1.1	
80	2.0	2,396	0.9	33	0.8	29	2.3	9	−0.2	
Total		7,758		1,068		964		5,799		257

† Negative value means less residue is produced than acquired to protect against sol loss at the indicated level.
‡ <0.1 metric tons/ha.
§ <1,000 metric tons in MLRA.
¶ No reported harvested area in MLRA.

this residue would also be available for the more restrictive systems. That is, all residue available for removal in system A1 was also considered available in systems A2, A3, A4, and A5; all residue available in system A2 was considered available in system A3; and all residue available in system A4 was considered available in system A5. The maximum amount of residue that could be removed from the combination of tillage systems was 59% of the total produced with over 85% of this amount obtainable from the systems (A1, A2, and A3) that required up to 1.68 metric tons/ha residue remaining on the surface.

Table 5—Percent of residue produced in MLRA's that is available for removal and percent area that produces sufficient residue to protect area against water erosion for the five tillage and residue systems.†

	Residue available					Area protected				
MLRA	A1	A2	A3	A4	A5	A1	A2	A3	A4	A5
	%									
102	57	62	68	66	72	60	66	81	72	86
103	65	67	77	79	86	67	71	98	93	98
104	51	52	60	56	68	55	57	78	63	94
105	28	36	42	45	51	36	48	64	61	78
106	13	17	20	19	23	14	20	34	22	54
107	20	26	27	26	29	20	30	37	31	42
108	29	42	50	42	53	29	46	62	46	67
109	6	16	20	23	26	18	33	52	47	60
110	45	61	66	61	70	46	67	79	68	89
111	36	52	58	57	68	36	57	73	65	91
112	20	30	34	34	39	27	43	75	49	92
113	1	10	20	29	32	2	16	49	40	59
114	6	24	32	31	41	8	32	62	41	73
115	8	36	42	41	46	12	48	61	53	73
Weighted avg.	35	45	52	51	59	36	50	69	59	78

† A1 = conventional tillage (all residue removed.
A2 = conservation tillage (1.68 metric tons/ha residue remaining).
A3 = conservation tillage (3.9 metric tons/ha residue remaining).
A4 = no till (1.68 metric tons/ha residue remaining).
A5 = no till (3.9 metric tons/ha residue remaining).

The percent area adequately protected against water erosion increased from 36% for system A1 to 78% for system A5, demonstrating the effectiveness of tillage systems with crop residue management in controlling soil erosion. For the remaining 22% of the cultivated area in the Corn Belt, additional conservation techniques will be required to reduce soil loss to acceptable levels. Conservation techniques may include practices like contour farming, strip cropping, or terracing that reduce the P factor to <1. In extreme cases where the combination of tillage systems and conservation practices do not reduce soil loss to an acceptable level, a change in crop rotations may be necessary.

The amounts of residue available for removal and percent area adequately protected against wind erosion in the Great Plains for the four simulated conditions is shown in Table 6. About 56% of the area produces sufficient residue to protect against wind erosion for condition 2, where E equals 11.2 metric tons/ha per year and K equals 1.0. As the amount of allowable soil loss increases, conditions 1 to 2 and 3 to 4, the amount of residue that can be removed increases, but long-term consequences on soil degradation must be considered at

Table 6—Percent of residue produced in the MLRA's that is available for removal and percent area that produces sufficient residue to protect area against wind erosion for conditions 1, 2, 3, and 4.†

MLRA	Residue available				Area protected			
	1	2	3	4	1	2	3	4
	%							
52	0	0	13	35	0	0	100	100
53	0	1	8	45	0	19	43	98
54	1	6	23	52	28	28	100	100
55	3	7	34	68	31	31	92	100
56	23	35	58	82	96	100	100	100
57	54	70	100	100	100	100	100	100
58	10	22	46	70	100	100	100	100
59	<1	3	27	49	8	25	100	100
60	4	15	40	65	72	90	100	100
61	19	28	54	70	76	92	98	100
62	<1	<1	37	67	0	83	98	100
63	5	13	40	63	68	69	90	100
64	13	23	47	71	82	99	99	99
65	29	36	51	65	89	89	99	99
66	10	18	35	64	54	61	61	100
67	6	8	26	47	12	12	93	95
68	16	20	33	52	31	31	100	100
69	4	5	9	27	9	9	23	79
70	<1	<1	5	13	0	0	9	69
71	39	45	61	79	94	94	100	100
72	7	10	30	45	19	91	91	100
73	8	31	42	61	78	78	78	100
74	33	40	60	86	74	74	100	100
75	36	45	64	88	69	100	100	100
76	29	40	68	100	56	100	100	100
77	6	8	14	29	10	11	60	100
78	<1	<1	26	46	37	75	81	100
79	14	22	39	56	83	83	83	100
80	45	55	72	93	94	94	100	100
Weighted avg.	15	21	38	60	40	56	81	99

† 1—E = 6.7 metric tons/ha, K = 1.0.
2—E = 11.2 metric tons/ha, K = 1.0.
3—E = 11.2 metric tons/ha, K = 0.5.
4—E = 22.4 metric tons/ha, K = 0.5.

the higher soil-loss rates. Changes in soil roughness, conditions 2 to 3, will change allowable residue removal and percent of area adequately protected. Ideally a roughness value of 0.5 would be maintained, but this is not always possible, particularly under summer fallow.

A large percentage of the residue that is available for removal from conventional tillage in the Corn Belt and for condition 2 in the Great Plains is located in a few MLRA's (Tables 3 and 4), indicating the lower erosion potential in these areas. However, erosion potentials are based on average values and do not take into account the possible extremes. Mutchler et al. (11) reported the soil loss on a Barnes loam (Udic Haploborolls) in West Central Minnesota in 1 year of a 10-year study exceeded the soil loss from the other 9 years combined. The calculated soil loss for the Great Plains only considers soil loss by wind, but water erosion can also be a problem and may be the main problem in some areas, especially on the eastern edge of the Great Plains. In areas where water erosion presents a problem, residue removal rates should be based on the combined erosion potentials.

Although the amounts of residue available for removal are based on average production values from current production statistics, these values will vary with cropping practices and climatic conditions and will not necessarily be correct for all years or for one location. Therefore, caution should be exercised before large-scale residue removal is practiced on a continuing basis.

In summary, considering the erosion protection supplied by crop residues as demonstrated by application of the USLE and WEE, we must conclude that the residue of straw and stover of the grain-producing crops in the Corn Belt and Great Plains is a valuable resource to the soil. Any removal of residues from the field for alternate uses should be considered in terms of possible soil erosion and environmental pollution hazards with a full understanding of the possible consequences.

LITERATURE CITED

1. Adams, J. E. 1966. Influence of mulches on runoff erosion, and soil moisture depletion. Soil Sci. Soc. Am. Proc. 30:110–114.
2. Alich, J. A., Jr., and R. E. Inman. 1974. Effective utilization of solar energy to produce clean fuel. Report to Natl. sci. Found., Grant no. 38723. Stanford Res. Inst., Menlo Park, Calif.
3. Austin, M. E. 1965. Land resource regions and major land resource areas of the United States. USDA Handbk. no. 296. U.S. Government Printing Office, Washington, D.C.
4. Chepil, W. S. 1944. Utilization of crop residues for wind erosion control. Sci. Agric. 24:307–319.
5. Chepil, W. S., N. P. Woodruff, F. H. Siddoway, D. W. Fryrear, and D. V. Armbrust. 1963. Vegetative and nonvegetative materials to control wind erosion. Soil Sci. Soc. Am. Proc. 27:86–89.
6. Chepil, W. S., N. P. Woodruff, F. H. Siddoway, and Leon Lyles. 1960. Anchoring vegetative mulches. Agric. Eng. 41:754–755, 759.
7. Englehorn, C. L., A. W. Znigg, and N. P. Woodruff. 1952. The effects of plant residue cover and clods structure on soil losses by wind. Soil Sci. Soc. Am. proc. 16:29–33.
8. Kramer, L. A., and L. D. Meyer. 1969. Small amount of surface mulch reduce soil erosion and runoff velocity. Trans. ASAE 12: 638–641, 645.
9. Mannering, J. V., and L. D. Meyer. 1963. Effects of various rates of surface mulch on infiltration and erosion. Soil Sci. Soc. Am. Proc. 27:84–86.
10. Meyer, L. D., W. H. Wischmeier, and G. R. Foster. 1970. Mulch rates required for erosion control on steep slopes. Soil Sci. Soc. Am. Proc. 34:928–931.
11. Mutchler, C. K., R. E. Burwell, and L. C. Staples. 1976. Runoff and soil losses from Barnes soils in the Northwestern Corn Belt. ARS-North Central Region Bull. No. 36.
12. Siddoway, F. H., W. S. Chepil, and D. V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. Trans. ASAE 8:327–331.
13. Skidmore, E. L., P. S. Fisher, and N. P. Woodruff. 1970. Wind erosion equation: Computer solution and application. Soil Sci. Soc. Am. Proc. 34:931–935.
14. Steffgen, F. W. 1974. Energy from agricultural products. *In* D. E. McCloud (ed.) A New look at energy sources. ASA Special Publ. no. 22, Am. Soc. Agron., Madison, Wis.
15. U.S. department of Agriculture. 1967. National inventory of soil and water conservation needs. USDA Stat. Bull. no. 461. U.S. Government Printing Office, Washington, D.C.
16. Wischmeier, W. H. 1973. Conservation tillage to control water erosion. *In* Conservation tillage. Proc. Natl. Conf. Soil Conserv. Soc. Am., Ankeny, Iowa.
17. Wischmeier, W. H., and D. D. Smith. 1965. Predicting rainfall-erosion losses from cropland east of the Rocky Mountains. USDA Handbk. no. 282. U.S. Government Printing Office, Washington, D.C.
18. Woodruff, N. P., and F. H. Siddoway. 1965. A wind erosion equation. Soil Sci. Soc. Am. Proc. 29&602–608.