tions in the Pacific Northwest.

Our projections repeatedly revealed that water erosion control can be attained by a choice of managements in a conservation system. On slopes less than 10 percent, there is leeway to use individual practices or a combination of tillage and residue management, contouring, or terracing. Generally, contouring with reduced tillage and more surface residues will suffice. Slopes of 10 to 20 percent require that all three alternatives be used, along with greater amounts of surface residues. Where slopes exceed 20 percent, it will be difficult to keep soil erosion below tolerance in wheat-fallow and wheat-pea sequences.

Tillage and residue management practices X_4 and X_6 (Table 2) are difficult to achieve. A surface cover of 1,960 kilograms per hectare (1,750 lb/a) under practice X_4 requires about 4,000 kilograms per hectare (3,560 lb/a) of straw production. This cover management approaches the drastically reduced and no-till procedures for which Papendick and Miller (*10*) cautioned that technology is not adequate. A similar technological inadequacy restricts use of management practice X_6 in the wheat-pea sequence because standing stubble produces excessively wet soil conditions in spring, delays pea planting, and inhibits pea growth, especially in MLRA B9.

An overall assessment of soil erosion in the four MLRAs could be improved also by estimating soil erosion on the nontilled adjacent cropland and uncultivated forest and range land. Assessment would also be improved with a complete analysis for the MLRAs in the Northwest Wheat and Range Region (Figure 1). Climatic and topographic variations and resulting soil erosion within a MLRA could be assessed.

We did not address year-to-year variations in soil erosion and crop residue production. The USLE is correctly applied when it projects average annual soil losses in response to average rainfall, plus runoff energy, cover, and management factors. Residue production for a MLRA has a year-to-year coefficient of variability ranging from 25 to 50 percent, depending on crop. Thus, tillage for control of surface residues would vary from year-to-year. This variation, combined with the low yields of residues scattered over a large land area, detracts from profitable use of residues for servicing bioenergy needs (*4*).

In all MLRAs in this study area, crop residues on the soil surface enhance soil water storage during mild, wet winters. Our conservative estimate of this benefit is 150 kilograms of grain per hectare (134 lb/a). Crop residues are needed for wind erosion control in MLRA B7, especially.

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78-366-J

Crop residue management for wind erosion control in the Great Plains

E. L. Skidmore, M. Kumar, and W. E. Larson

ABSTRACT: We delineated those croplands in the Great Plains where crop residues might be removed without exposing the soil to wind erosion. On the basis of grain yield data, we estimated the residues produced per unit of land by crops. We determined mean soil erodibility and climatic factors for each of 29 major land resource areas and used these factors in the wind erosion equation to estimate the residues needed to control wind erosion. The residues produced in excess of those needed for soil conservation depend on the kind and amount of residues, soil erodibility, climate, tillage management, and judgment of erosion and degradation hazard.

WE used the wind erosion equation, crop acreages, and crop yield data to analyze the effects of removing crop residues from the land in the Great Plains. Larson (*10*) provided the general background and objectives of this study.

Calculation procedures

The Great Plains include three land resource regions: Northern Great Plains Spring Wheat Region (F), Western Great Plains Range and Irrigated Region (G), and Central Great Plains Winter Wheat and Range Region (H). These regions include 29 major land resource areas (MLRAs) and constitute most of 416 counties in 11 states (Figure 1).

We obtained acreage figures and grain yield data from the Statistical Reporting Service and state boards of agriculture for the major residue-producing crops—wheat, barley, oats, corn, and sorghum. We further subdivided the wheat crops into six categories—fallow and continuous systems for winter, spring, and durum wheat—then we computed the three-year (1973-75) average yield and crop area for each crop class by county.

To calculate the crop residues produced on a per acre basis, we multiplied grain

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yield by straw/grain ratios.

We calculated the residues needed to control wind erosion using the wind erosion equation (*6, 13*). This equation is E = f(I, K, C, L, V), where E is erosion, I is soil erodibility, K is the ridge roughness factor, C is the climatic factor, L is field length, and V is the equivalent quantity of vegetative cover (*16*).

We estimated average erodibility for each MLRA from information on soil textural classification and area given by the Soil Conservation Service (SCS) Conservation Needs Inventory. We calculated an average climatic factor for each MLRA from the average annual climatic factor (*16*) of the counties comprising the respective MLRA. Fields were assumed wide to show that any further increase in width would not increase the wind erosion hazard. This condition usually occurs in a field between 500 and 1,000 meters (1,640-3,280 ft) wide.

We solved the wind erosion equation for equivalent vegetative cover using the following combinations of potential average annual soil loss and surface roughness: 3.0, 1.0; 5.0, 1.0; 5.0, 0.5; 10.0, 0.5. Surface roughness values of 1.0 and 0.5 represent smooth and rough conditions, respectively. We converted the equivalent vegetative cover to flat, small-grain residues for wheat, barley, and oats and to standing stubble [25 cm (10 in)] for corn and sorghum.

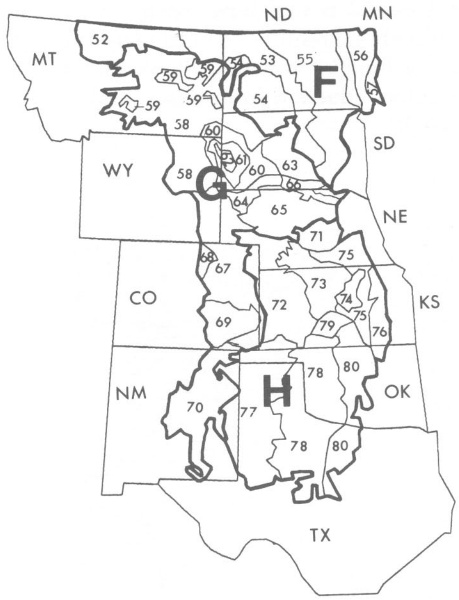

Figure 1. Land resource regions F, G, H and MLRAs 52-80 in the Great Plains (*2*).

Not all residues produced by a crop remain on the soil surface during the season when wind erosion is a hazard. Tillage (*3, 4, 5*) and weathering (*7*) both reduce surface residues.

We estimated the fraction of residues remaining after tillage and weathering as follows: continuous wheat, 0.75; fallow wheat, 0.50; barley, 0.60; oats, 0.60; corn, 0.80; and sorghum, 0.80.

The quantity of residues produced beyond that needed to control wind erosion for the specified conditions can be obtained with the equation: SR = RP − RN/RR, where SR is surplus residues, RP is residue produced, RN is residue needed, and RR is the fraction of residues produced that remains to provide wind erosion protection.

Results and discussion

Tables 1 and 2 show the amounts of residue that can be removed from wide, smooth fields of barley, oats, corn, grain sorghum, and wheat grown in the various MLRAs of the Great Plains without creating a wind erosion hazard of more than 11.2 metric tons per hectare per year (5.0 t/a/yr). Figures 2 through 6 show areas where crop residues are insufficient for wind erosion control or in surplus for this purpose. Our work also involved other combinations of surface roughness and tolerable wind erosion, and we determined amounts of nitrogen, phosphorus, and potassium in the crop residues produced in each MLRA.

Kinds and amounts of residue. The more residues produced, the more residues available for uses other than conservation, as long as other conditions remain unchanged. MLRA 71 produces the most wheat residue per hectare, yielding a relatively large surplus. MLRA 72 also produces a lot of wheat residue, but not enough to meet wind erosion control

Table 1. Harvested area, residues produced, and residues available compared with those needed to control wind erosion on wide fields of barley, oats, corn, and grain sorghum in the MLRAs of the Great Plains.*

	Barley			Oats			Corn			Sorghum		
	Harvested	Residues		Harvested	Residues		Harvested	Residues		Harvested	Residues	
MLRA	Area (kha)	Produced (t/ha)	Available (t/ha)	Area (kha)	Produced (t/ha)	Available (t/ha)	Area (kha)	Produced (t/ha)	Available (t/ha)	Area (kha)	Produced (t/ha)	Available (t/ha)
52	245.1	2.3	−0.6	25.2	2.5	−0.5	0.1	3.0	−1.2	0	0	−4.2
53	148.5	2.4	0	223.5	2.5	0.1	43.7	1.7	−1.9	4.1	1.5	−2.1
54	69.8	2.7	0.4	126.8	2.6	0.4	2.5	1.9	−1.5	0	1.1	−2.3
55	577.3	2.5	0.4	455.8	2.7	0.6	234.7	2.0	−1.3	17.9	2.0	−1.2
56	464.5	3.3	1.3	239.3	3.1	1.2	82.4	3.5	0.4	0	0	−3.0
57	38.6	3.0	2.2	90.8	3.0	2.2	32.5	3.3	1.9	0	0	−1.4
58	64.3	2.9	0.6	24.8	2.9	0.6	2.7	4.5	1.0	0	0	−3.5
59	54.9	3.1	0.3	26.2	3.1	0.3	0.5	4.1	0.2	0	0	−3.9
60	5.5	2.1	−0.2	6.4	2.6	0.3	4.0	4.8	1.4	0.3	1.5	−2.0
61	2.6	1.8	−0.3	6.4	2.1	0	0.9	2.8	−0.5	0.2	1.2	−2.1
62	0.2	2.1	0	0.6	2.4	0.2	0.1	3.0	−0.4	0	1.2	−2.2
63	9.9	2.2	0	38.6	2.3	0	5.3	2.4	−1.0	18.7	1.6	−1.8
64	3.9	2.3	0.1	8.3	2.3	0.1	7.0	4.7	1.3	0.5	1.4	−2.0
65	2.2	2.8	0.2	10.4	2.4	−0.2	99.2	5.9	2.1	2.0	2.2	−1.4
66	9.2	2.3	0.2	36.1	2.8	0.7	32.8	2.1	−1.2	14.9	1.9	−1.3
67	27.2	2.8	0	13.0	2.4	−0.4	113.7	5.9	1.9	46.0	1.5	−2.4
68	4.6	3.6	0.9	0	0	−2.8	28.6	6.5	2.6	0.4	2.3	−1.7
69	4.5	3.4	0.5	0.7	2.6	−0.3	14.5	6.0	1.9	42.7	2.4	−1.6
70	0.9	2.7	−0.7	0	0	−3.4	4.6	4.9	0	15.2	1.6	−3.3
71	1.2	2.6	0.5	5.9	2.7	0.6	318.0	6.0	2.8	23.7	2.6	−0.7
72	5.9	2.7	−0.4	4.5	2.4	−0.7	464.6	6.4	2.0	205.4	3.2	−1.2
73	1.9	2.8	0.3	7.2	2.8	0.3	144.5	6.3	2.6	285.5	2.7	−1.0
74	0.6	3.0	1.0	5.5	2.5	0.6	14.5	4.4	1.3	112.6	2.9	−0.1
75	2.4	3.1	1.3	22.8	3.1	1.3	568.1	6.5	3.5	602.4	3.3	0.3
76	4.4	3.2	1.6	11.5	2.5	1.0	29.4	3.5	0.9	190.9	2.9	0.4
77	12.1	3.6	0.4	4.4	2.5	−0.7	280.5	7.4	2.8	1,287.3	3.8	−0.7
78	29.9	2.3	−0.4	66.4	2.3	−0.3	1.2	5.7	2.0	297.9	2.3	−1.5
79	1.9	2.9	0.3	1.2	2.4	−0.3	18.8	6.7	2.8	89.9	2.7	−1.1
80	36.7	2.7	1.0	34.1	2.6	0.8	4.2	5.1	2.3	77.2	2.6	−0.2

*T = 11.2 t/ha/yr (5.0 t/a/yr); K = 1.0.

needs. The main differences between these two MLRAs are climatic factors and cultural practices. Representative climatic factors are 32 and 73 for MLRAs 71 and 72, respectively. In addition almost all of MLRA 72 is in fallow wheat, which requires more residue to control wind erosion for a longer time and allows for greater residue reduction from tillage and weathering.

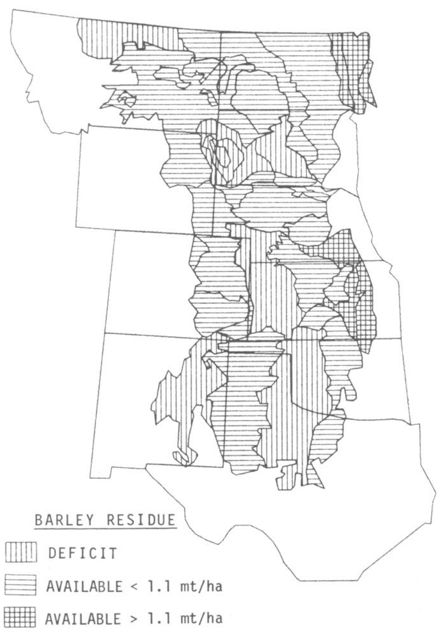

Figure 2. Area in the Great Plains where barley residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for controlling potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

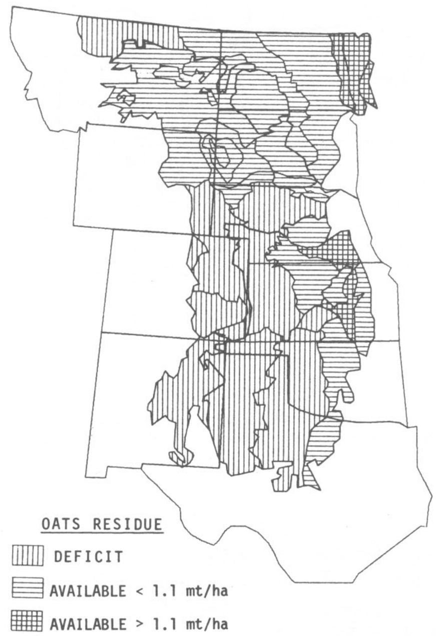

Figure 3. Area in the Great Plains where oats residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for limiting potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

Compared with corn and sorghum, lesser amounts of small grain residues are needed to control wind erosion. Table 1 shows about the same per hectare production of barley and sorghum in MLRA 71. However, barley residues are available at 500 kilograms per hectare (446 lb/a), while sorghum residues are deficient by almost 700 kilograms per hectare (624 lb/a).

Soil erodibility. We used a single erodibility value (weighted mean) for each MLRA. Each MLRA contains fields more erodible and less erodible than this single value. The more erodible fields obviously require greater quantities of residues to control erosion. Consequently fewer residues are available for other uses.

The Nebraska Sand Hills, MLRA 65, have the most erodible soils encountered in our study. Mixed Sandy and Silty Tableland, MLRA 64, has essentially the same climatic factor. More residues are needed for MLRA 65 than for 64. Oat residue production was nearly equal in these two MLRAs, yet MLRA 65 needed, on the average, 0.2 metric ton per hectare (178 lb/a) more residues than the amount produced to control wind erosion. MLRA 64 produced a surplus of 0.1 metric ton per hectare (89 lb/a) (Table 1). That additional residues are needed for MLRA 65 is apparent also from the fallow wheat data (Table 2).

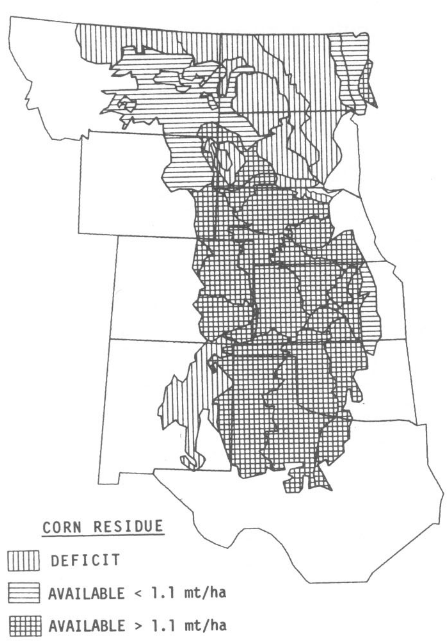

Figure 4. Area in the Great Plains where corn residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for limiting potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

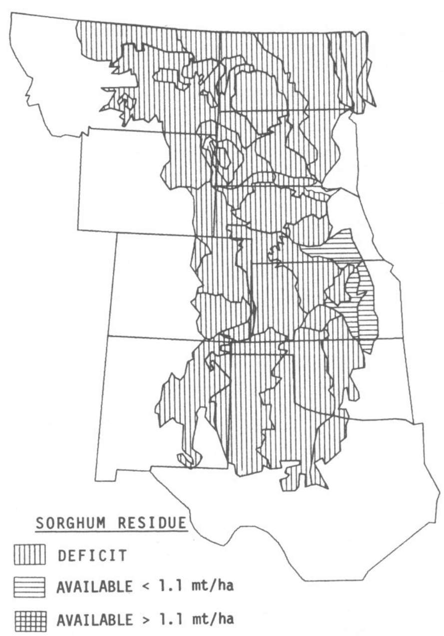

Figure 5. Area in the Great Plains where grain sorghum is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for limiting potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

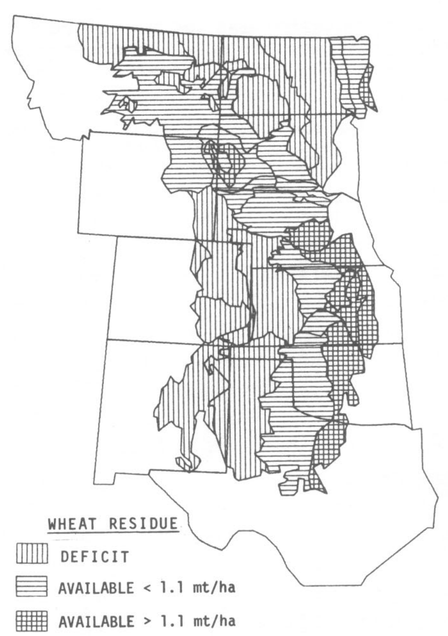

Figure 6. Area in the Great Plains where wheat residue is deficit and surplus at less than and greater than 1.1 metric tons per hectare (1,000 lb/a) for limiting potential average annual soil loss from wind erosion to 11.2 metric tons per hectare per year (5.0 t/a/yr) on wide, smooth fields.

Table 2. Harvested area, residues produced, and residues available compared with those needed to control wind erosion on wide fields of continuous and fallow wheat (winter, spring, durum) in the MLRAs of the Great Plains.*

	Total Wheat			Continuous Wheat			Fallow Wheat		
	Harvested Area	Mean Residues		Harvested Area	Mean Residues		Harvested Area	Mean Residues	
MLRA	(kha)	Produced (t/ha)	Available (t/ha)	(kha)	Produced (t/ha)	Available (t/ha)	(kha)	Produced (t/ha)	Available (t/ha)
52	803.9	2.8	−0.4	252.8	2.1	−0.3	554.3	3.2	−0.4
53	1,478.1	1.7	−0.8	437.4	1.3	−0.6	1,040.7	1.9	−0.9
54	510.1	1.9	−0.6	97.5	1.4	−0.4	412.7	2.0	−0.7
55	2,025.5	1.9	−0.3	829.2	1.6	0	1,196.3	2.0	−0.5
56	1,150.9	2.7	0.9	745.1	2.6	1.9	405.8	2.8	0.5
57	65.9	2.4	1.7	42.9	2.4	1.7	22.9	2.6	1.6
58	182.8	3.2	0.7	50.0	2.4	0.6	132.8	3.5	0.7
59	241.5	2.8	−0.1	86.3	2.1	−0.1	155.2	3.2	0
60	25.2	2.9	0.4	5.4	2.1	0.3	19.8	3.2	0.4
61	29.7	3.6	1.2	4.4	2.5	0.9	25.3	3.7	1.2
62	0.8	2.9	0.5	0.2	1.9	0.2	0.6	3.3	0.7
63	156.1	3.0	0.5	47.5	2.1	0.3	108.7	3.3	0.6
64	49.0	3.3	0.8	7.4	2.4	0.7	41.6	3.5	0.9
65	17.5	3.5	0.6	3.4	2.7	0.7	14.0	3.7	0.6
66	30.8	3.2	1.0	11.9	2.2	0.5	18.8	3.8	1.3
67	747.5	2.8	−0.3	147.0	2.2	0	600.5	2.9	−0.4
68	74.6	2.6	−0.5	14.6	2.1	−0.1	59.9	2.7	−0.6
69	147.3	2.4	−0.8	28.9	1.9	−0.4	118.4	2.5	−0.9
70	30.2	2.0	−1.0	26.2	1.9	−0.9	4.0	2.6	−1.5
71	58.4	4.1	1.9	20.2	3.5	1.9	38.2	4.4	1.9
72	1,728.9	3.6	0	95.5	2.6	0.1	1,633.4	3.6	0
73	869.6	3.6	1.0	268.4	3.2	1.2	601.2	3.8	0.9
74	302.1	3.6	1.9	226.6	3.5	1.9	75.5	4.0	1.7
75	715.8	3.8	2.2	526.7	3.6	2.1	189.1	4.5	2.3
76	200.4	3.4	2.2	200.4	3.4	2.2	0	0	0
77	1,144.5	2.8	−0.9	65.1	2.6	0	1,079.4	2.8	−1.0
78	1,196.3	2.7	0	589.5	2.6	0.4	606.9	2.8	−0.3
79	439.2	3.3	0.8	270.3	3.1	1.0	168.9	3.6	0.4
80	1,198.4	3.4	1.9	1,110.7	3.4	2.0	87.7	3.9	1.8

*T = 11.2 mt/ha/yr (5.0 t/a/yr); K = 1.0.

Erosion hazard. As the soil loss restriction declines, the residues needed for wind erosion control increase (Table 3). For example, a soil loss restriction of 6.7 metric tons per hectare per year (3.0 t/a/yr) requires almost 340 kilograms per hectare (303 lb/a) more small-grain residue than a restriction of 11.2 metric tons per hectare per year (5.0 t/a/yr). Considerably more residues can be removed if higher soil losses are tolerated. But what are the long-term consequences?

Tillage. If fields are cropped so they are rough during the wind erosion season, less residue is needed to control wind erosion. The only difference between conditions 2 and 3 in table 3 is the roughness factor. The soil ridge roughness factor is about 0.5 when K_r in the following equation is between 2.0 and 5.0 (*1, 16*):

$$K_r = \frac{\text{ridge height/ridge spacing}}{\text{standard ratio (1:4)}} \times \text{ridge height}$$

In an emergency, some nonsandy soils can be chiseled to produce rough surfaces (*14*). But emergency tillage, a temporary measure that can injure a crop, should be used only after other wind erosion control methods have failed (*15*).

Climate. As precipitation increases from west to east across Kansas, the wind erosion climatic factor decreases. The calculated climatic factors for MLRAs 72, 73,

Table 3. Residues produced in excess of those needed to control wind erosion by major residue-producing crops for various conditions.

Land Resource Area	Harvested Area (million ha)	Excess Residue Produced by Condition*			
		1	2	3	4
		kg/ha			
Wheat					
52	0.81	− 691	− 362	437	1,048
53	1.48	−1,117	− 785	− 28	730
55	2.03	− 642	− 324	492	1,217
56	1.15	566	896	1,555	2,214
72	1.74	− 444	− 33	897	1,514
73	0.87	620	510	1,751	2,411
77	1.14	−1,397	− 933	− 6	562
78	1.22	− 209	54	844	1,458
80	1.22	1,650	1,977	2,559	3,285
Barley					
52	0.24	− 919	− 613	132	731
53	0.14	− 250	57	757	1,458
55	0.57	134	441	1,229	1,929
56	0.45	992	1,342	2,043	2,743
Oats					
53	0.22	− 189	118	818	1,519
54	0.13	57	364	1,108	1,721
55	0.45	275	581	1,370	2,070
56	0.24	844	1,194	1,895	2,595
Corn					
55	0.23	−1,620	−1,269	− 306	745
71	0.32	2,455	2,805	3,768	4,819
72	0.47	1,530	2,056	2,931	3,632
75	0.57	3,063	3,501	4,552	5,777
77	0.28	2,147	2,847	3,811	4,423
Sorghum					
72	0.23	−1,684	−1,158	− 283	417
73	0.28	−1,279	−1,017	− 141	734
75	0.61	− 139	299	1,350	2,576
77	1.29	−1,419	− 718	245	858
78	0.30	−1,775	−1,512	− 724	151

*Conditions 1, 2, 3, and 4 represent potential average annual soil losses of 6.7, 11.2, 11.2, and 22.4 metric tons per hectare per year (3.0, 5.0, 5.0, and 10.0 t/a/yr) with surface roughness factors of 1.0 (smooth), 1.0, 0.5 (rough), and 0.5, respectively.

74, 75, and 76, from west to east across Kansas, are 73, 50, 30, 28, and 20, respectively. As the climatic factor decreases, the residues needed to control wind erosion decrease. In the Central Plains, residues are insufficient in the west, increase as one moves easterly, and are available in the east [greater than 1.1 metric tons per hectare (1,000 lb/a)] for wind erosion control under specified conditions (Figure 6).

These calculations are for wind erosion only. Areas with surplus residues for wind erosion control may show a deficit of residues for water erosion control.

For most soils in the Great Plains the critical level of residues needed to maintain a favorable level of organic matter that enhances soil physical properties is not well defined. In general, however, soils that are now cropped, rather than in native vegetation, have less organic matter and other associated physical properties that are less favorable (*9, 11, 12*). Crop residues that remain on a field and are eventually incorporated into the soil promote favorable physical conditions.

Maintenance of surface straw mulches also contributes to improved water storage efficiencies in summer fallow (*8*). Water storage efficiencies in summer fallow have nearly doubled over the past 50 years because of better stubble-mulching and weed control.

Residues of grain-producing crops in the Great Plains are valuable resources insofar as the soil is concerned. Better management of these residues would enhance their ability to conserve soil and water and increase soil productivity. Removing residues from fields for other uses should be done judiciously and with an understanding of the consequences.

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Crop residue effects on runoff

C. A. Onstad and M. A. Otterby

ABSTRACT: Crop residues on the soil surface decrease runoff from all storm sizes and eliminate runoff from most small storms. Runoff reductions and consequent increases in soil water storage are greatest on less permeable soils. The increase in soil water storage is greatest in the southeastern U.S.

CROP residues generally are returned to the soil. However, attention recently has focused on the possible use of crop residues as an energy source. Removal of residues for this purpose would have an immediate effect on erosion and soil nutrient relations (*1, 4, 5, 6, 10*). Residue removal would also affect soil productivity over the long term, although the magnitude of this effect is not clearly defined.

Residues left on the soil surface through the use of conservation tillage reduce runoff (*3, 8, 11, 12, 13, 14*). Most documentation of this fact is the result of plot tests or small watershed studies using either natural or simulated rainfall over short periods of time. In the SEA-team study we attempted to use available data in conjunction with a recently developed method to estimate the regional effects of residue management on mean annual runoff from agricultural areas.

The runoff estimation method

Using the Soil Conservation Service (SCS) curve number method, Woolhiser (*18*) estimated potential average annual direct runoff in the eastern U.S. His simulation employed daily rainfall records from about 50 different locations.

The method uses a curve number to represent the average surface storage capability for different soil cover complexes. These numbers vary according to the land use practices on four hydrologic soil groups (*16*). These soil groups classify soil associations with regard to runoff potential. The groups are defined as follows (*16*):

Group A (low runoff potential). Soils having high infiltration rates even when thoroughly wetted and consisting chiefly of deep, well to excessively drained sands and gravels. These soils have a high rate of water transmission.

Group B. Soils having moderate infiltration rates when thoroughly wetted and consisting chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.

Group C. Soils having slow infiltration rates when thoroughly wetted and consisting chiefly of soils with a layer that impedes downward movement of water, or soils with moderately fine to fine texture. These soils have a slow rate of water transmission.

Group D (high runoff potential). Soils having very slow infiltration rates when thoroughly wetted and consisting chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near

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