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Crop Residue Management Systems

Chapter 2

Crop Residue Requirements to Control Wind Erosion[1]

E. L. SKIDMORE and F. H. SIDDOWAY

INTRODUCTION

Wind erosion persists as a serious problem in many parts of the world (Food and Agriculture Organization, 1960) and is the dominant problem on about 30 million ha of land in the United States (USDA, 1965). About 2 million ha are moderately to severely damaged each year.

Soil erosion by wind generally is considered as limited to semiarid and arid areas, although it can be a problem wherever soil, vegetative, and climatic conditions are conducive. These conditions exist when: (i) the soil is loose, dry, and reasonably finely divided; (ii) the soil surface is smooth and vegetative cover is absent or sparse; (iii) the field is sufficiently large; and (iv) the wind is sufficiently strong to move soil.

These conditions often prevail in semiarid and arid areas where precipitation is inadequate or where the seasonal or yearly vagaries prevent maintaining crops or residue cover on the land; however, they may also exist in subhumid and even humid areas.

Wind erosion damages the environment in several ways. It physically removes from the field the most fertile portion of the soil and, thus, lowers its productivity (Daniel & Langham, 1936; Lyles, 1975). Some eroded soil enters the atmospheric dustload (Hagen & Woodruff, 1973), which obscures visibility, pollutes the air, causes traffic hazards, fouls machinery, and injures animal and human health. Blowing soil also fills road ditches, reduces seedling survival and growth, lowers the marketability of many

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E. L. Skidmore and F. H. Siddoway are Soil Scientist, ARS-USDA, Manhattan, Kans. and Supervisory Soil Scientist, ARS-USDA, Sidney, Mont., respectively.

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vegetable crops, and increases the plant's susceptibility to and the transmission of some plant diseases.

The deleterious effects of wind erosion have prompted many investigations so as to better understand wind-erosion mechanics and to develop wind-erosion control practices. Practices to prevent or reduce wind erosion include: roughening the surface, producing a greater percentage of nonerodible aggregates, reducing field length, using wind barriers, and establishing and maintaining vegetative cover (Woodruff et al., 1972). Establishing and maintaining vegetation (residue and living cover) has become the "prime method" of wind-erosion control.

With the continuing decrease in the supply:demand ratio of petroleum and the financial squeeze on the cattlemen, pressure is increasing to use crop residue for feed,[2] fuel (Bolton, 1976), and substitutes for petroleum in industry (Jones, 1976). Therefore, we need to examine possible effects of removing residue on soil conservation, including wind erosion. We also need tillage and management systems to conserve our soil resource and maintain its productivity and, yet, leave a part of the residue available for purposes other than protecting the soil. In this paper we evaluate residue requirements to control wind erosion for various crop residue management systems, soil factors, and climatic conditions.

PRINCIPLES OF CONTROLLING WIND EROSION WITH CROP RESIDUES

Windspeed at the soil-air interface must be reduced to a threshold value below which no wind erosion will occur. Standing crop residue provides nonerodible elements, which absorb much of the shear stresses in the boundary layer. Lyles et al. (1974b), who controlled sand movement in a wind tunnel through various nonerodible rough elements, found that as the surface became stabilized, both total drag and roughness-element drag increased as particles eroded from the intervening surface and exposed the roughness elements. When particle movement ceased for a given free-stream velocity, drag on the intervening surface had been reduced to the threshold drag, while total drag and roughness-element drag had reached a maximum (Fig. 1). When crop residues are sufficiently high and dense to prevent intervening surface drag from exceeding threshold drag, soil will not erode.

Residue in the form of nonerodible elements changes the wind profile parameters and decreases windspeed at the surface. Consider the logarithmic law:

$$u = (u_*/\mathrm{k}) \ln [(z-z_d)/z_o], \qquad [1]$$

where u is the windspeed at height z, u_* is friction velocity, k is von Karman's constant, and z_d, the displacement height, is the distance from the

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[2] 1976 Cattle Feeders' Day, Garden City Branch Agric. Exp. Stn.; Roundup 1976, Ft. Hays Branch Agric. Exp. Stn.; and Cattlemens' Day 1976, Kansas Agric. Exp. Stn., all reported research of crop residues in livestock rations.

ground surface to the plane at which the momentum-transfer coefficient extrapolates to zero. The roughness parameter, z_o, is the distance from the displaced reference plane to the surface at which the wind profile extrapolates to zero.

Although the momentum-transfer coefficient and windspeed do not actually reach zero at z_d and $z_d + z_o$, respectively, knowing how much they increase with height of residue and vegetation on surface aids in

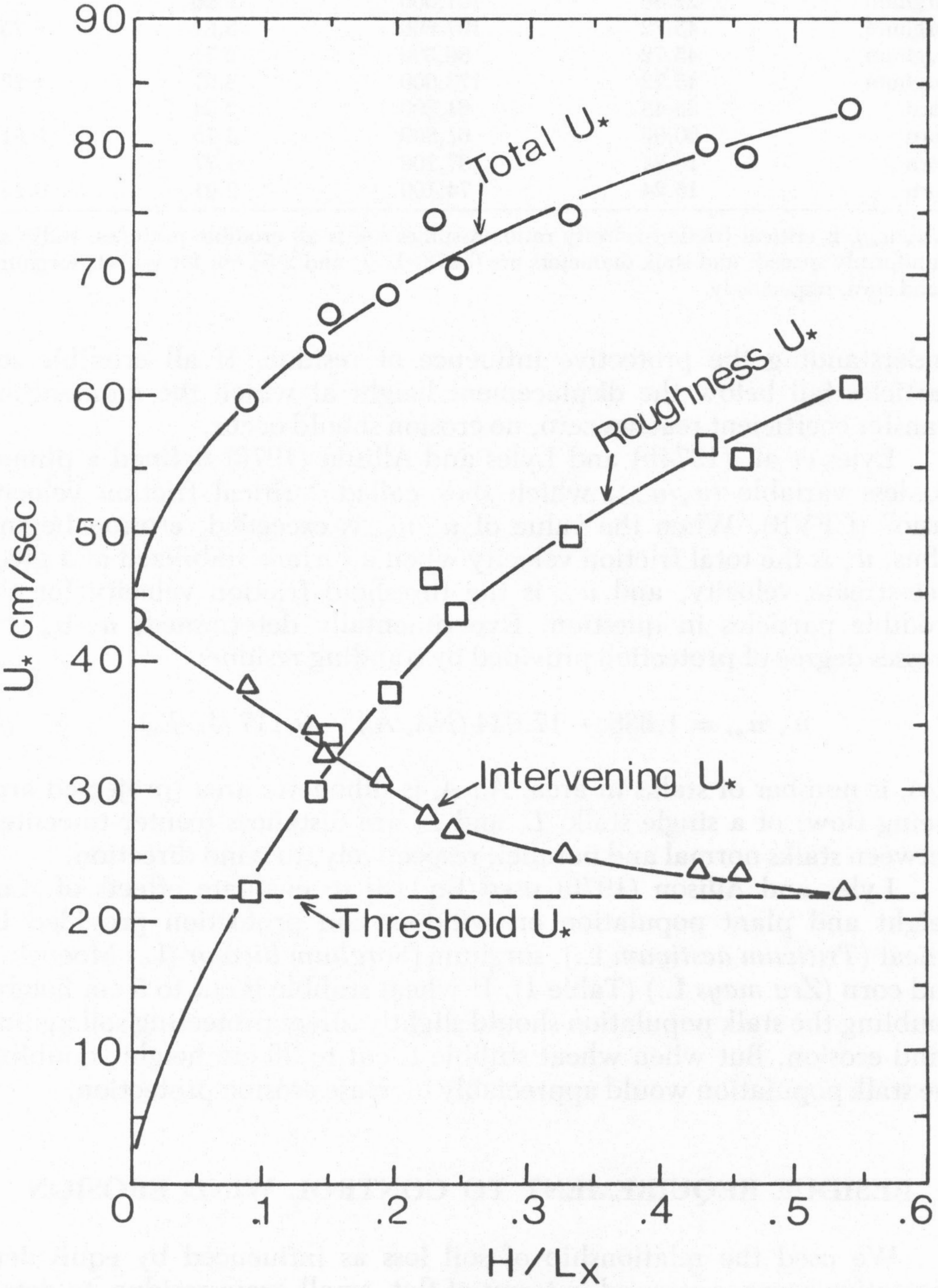

Fig. 1. Friction velocity (u_*) or drag changes as surface stabilizes by exposing nonerodible roughness elements. H is roughness element height and L_x is distance (3.49 cm) between nonerodible roughness elements (Lyles et al., 1974b).

Table 1. Wind-erosion protection provided by stalk height and plant population of several crops (Lyles & Allison, 1976)

Crop	Height	Plant population	$(u_*/u_{*t})_s$†	Change
	cm	stalks/ha		
Wheat	5.08	2,471,000	2.12	
Wheat	5.08	4,942,000	2.71	0.59
Wheat	30.48	2,471,000	5.09	
Wheat	30.48	4,942,000	8.66	3.57
Sorghum	22.86	107,600	2.26	
Sorghum	45.72	107,600	3.01	0.75
Sorghum	45.72	86,500	2.71	
Sorghum	45.72	173,000	3.91	1.20
Corn	30.48	61,800	2.34	
Corn	60.96	61,800	3.15	0.81
Corn	15.24	37,100	1.77	
Corn	15.24	74,100	2.01	0.24

† $(u_*/u_{*t})_s$ is critical friction-velocity ratio. Assumes soil is all erodible particles; stalks are uniformly spaced; and stalk diameters are 0.278, 1.77, and 2.54 cm for wheat, sorghum, and corn, respectively.

understanding the protective influence of residue. If all erodible soil particles fall below the displacement height at which the momentum-transfer coefficient reaches zero, no erosion should occur.

Lyles et al. (1974b) and Lyles and Allison (1976) defined a dimensionless variable (u_*/u_{*t}), which they called "critical friction velocity ratio" (CFVR). When the value of u_*/u_{*t} is exceeded, erosion begins. Thus, u_* is the total friction velocity when a surface stabilized at a given free-stream velocity, and u_{*t} is the threshold friction velocity for the erodible particles in question. Experimentally determined, u_*/u_{*t} expresses degree of protection provided by standing residue:

$$u_*/u_{*t} = 1.638 + 17.044\,(NA_s/A_t) - 0.117\,(L_y/L_x). \qquad [2]$$

N/A_t is number of stalks in area, A_t; A_s is silhouette area (projected area facing flow) of a single stalk; L_y and L_x are distances (center-to-center) between stalks normal and parallel, respectively, to wind direction.

Lyles and Allison (1976) used Eq. [2] to evaluate effects of stalk height and plant population on wind-erosion protection provided by wheat (*Triticum aestivum* L.), sorghum [*Sorghum bicolor* (L.) Moench.], and corn (*Zea mays* L.) (Table 1). If wheat stubble is cut to 5 cm height, doubling the stalk population should slightly affect protecting soil against wind erosion. But when wheat stubble is cut to 30 cm height, doubling the stalk population would appreciably increase erosion protection.

RESIDUE REQUIREMENT TO CONTROL WIND EROSION

We used the relationship of soil loss as influenced by equivalent vegetative cover, expressed in terms of flat, small-grain residue, to determine the amount of residue needed to control wind erosion for various

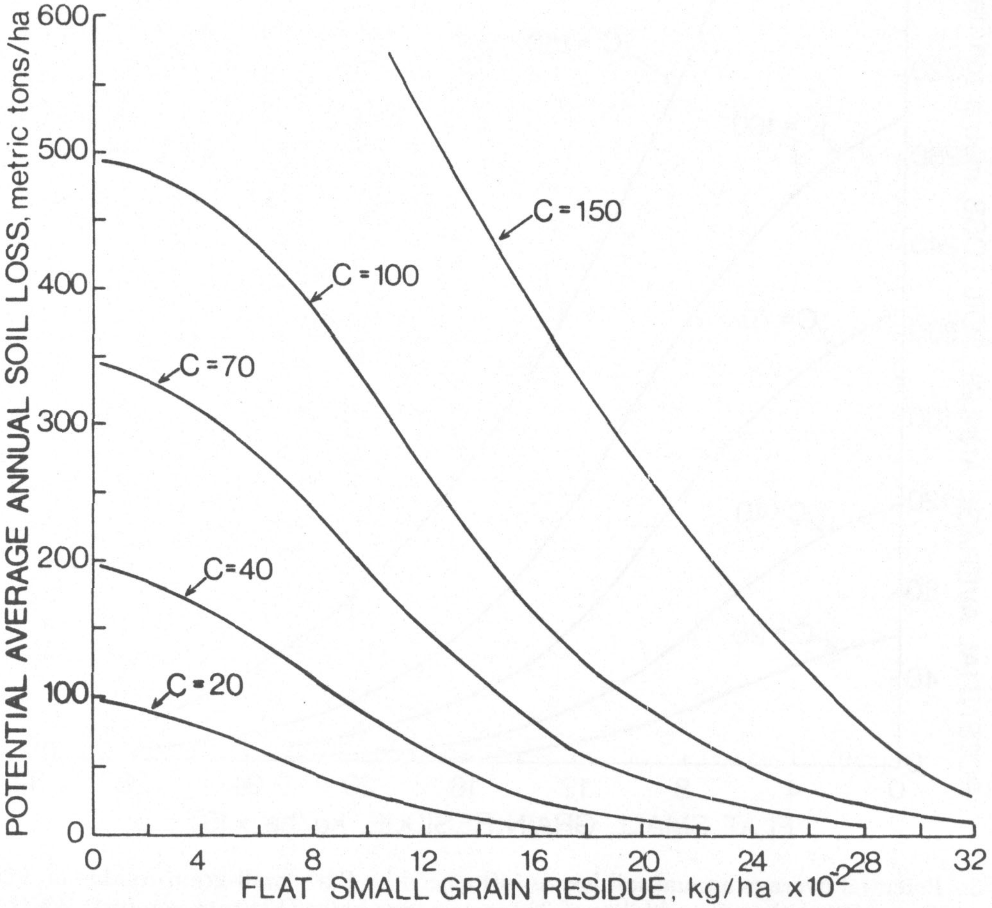

Fig. 2. Potential average annual soil loss as influenced by flat, small-grain residue and climatic factor (C) with soil erodibility of 493 metric tons/ha/yr (220 tons/acre/yr), wind erosion group (WEG) 1.

conditions. We calculated flat, small-grain residue quantities for combinations of climatic factor (20, 40, 70, 100, 150) and wind erodibility groups (WEG) of 1, 2, 3, and 6 corresponding to potential average annual soil losses of 493, 300, 193, and 108 metric tons/ha, respectively. Results are shown in Fig. 2, 3, 4, and 5.

The highly erosive soils in WEG 1 require large quantities of residue to control wind erosion. Fig. 2 shows that 1,120; 1,680; 2,350; 2,800; and 3,300 kg/ha of flat, small-grain residue are required to control potential average annual soil loss to 22.4 metric tons/ha/yr when climatic factors are 20, 40, 70, 100, and 150, respectively.

As the percentages of soil aggregates > 0.84 mm increase, soils become less erosive and require lesser amounts of residue to control wind erosion (Fig. 2, 3, 4, 5). The sands, loamy sands, and sandy loams erode easily, with potential average annual loss of more than 180 metric tons/ha/yr for bare, smooth, unsheltered fields when the climatic factor is 100. In the United States, excluding Hawaii and Alaska, more than 120 million ha of nonfederal, rural lands fall into those textural classifications (Table 2).

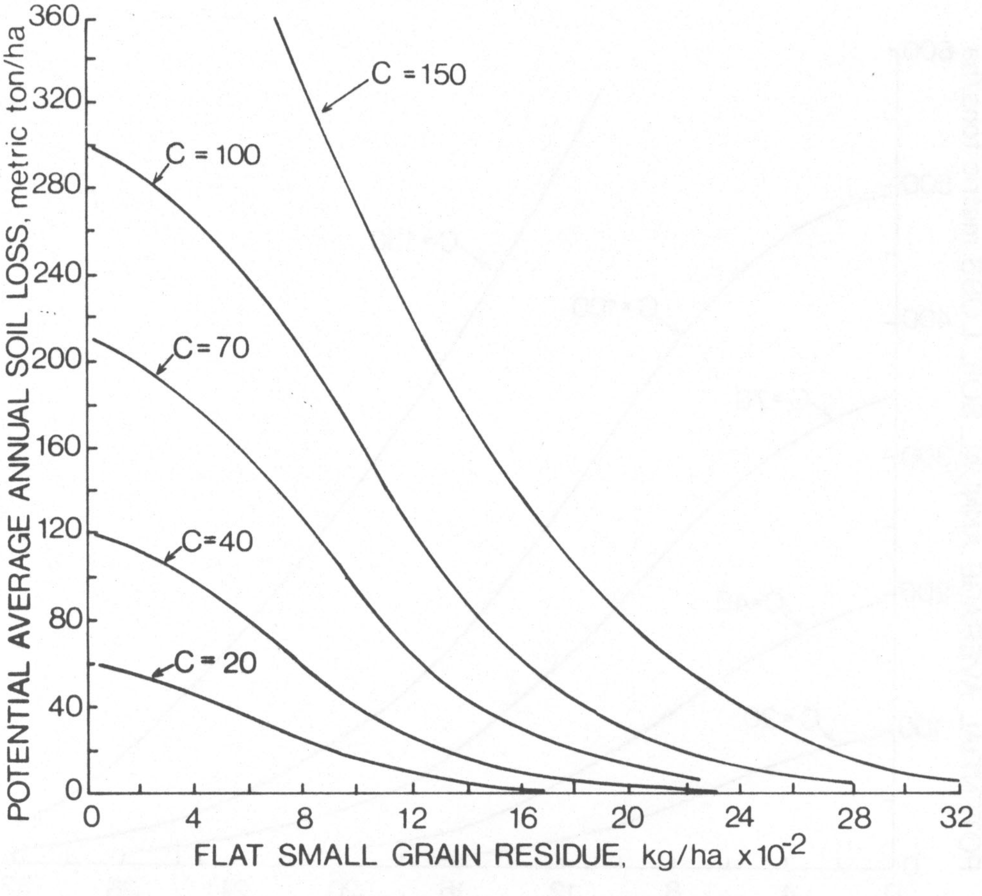

Fig. 3. Potential average annual soil loss as influenced by flat, small-grain residue and climatic factor (C) with soil erodibility of 300 metric tons/ha/yr (134 tons/acre/yr), WEG 2.

AMOUNT OF RESIDUE PRODUCED

The rule of thumb often used for estimating the quantity of residue produced by a winter wheat crop is a straw-grain ratio of 1.7 (100 lb of straw/bu of wheat or 45.40 kg of straw/27.24 kg of wheat). Black et al. (1974) reported a winter wheat straw-grain ratio of 2.0 and a spring wheat straw-grain ratio of 1.3. Frank et al. (1977) reported spring wheat straw-grain ratios in North Dakota ranging from 1.6 for irrigated wheat to 3.8 for dryland wheat grown in the shelter of a 2.5 m slat-fence wind barrier. The straw-grain ratio estimated from data of an 8-year study by Fenster and McCalla (1970) was 1.7.

The average yield of all wheat per harvested hectare in the United States is usually about 2,000 kg/ha, with several million hectares of seeded wheat unharvested (USDA, 1973). At 2,000 kg/ha of grain and 1.7 kg straw/kg of grain, straw yield is 3,400 kg/ha. Black et al. (1974) reported 3,590 and 2,020 kg straw/ha for winter and spring wheat, respectively, for Montana in 1970. Fenster and McCalla (1970) found the amount of wheat residue at the beginning of the fallow season ranged from 1,030 to 3,890 kg/ha in Nebraska.

Grain sorghum produces an amount of residue roughly equivalent to the amount of grain produced (E. L. Skidmore and L. J. Hagen, un-

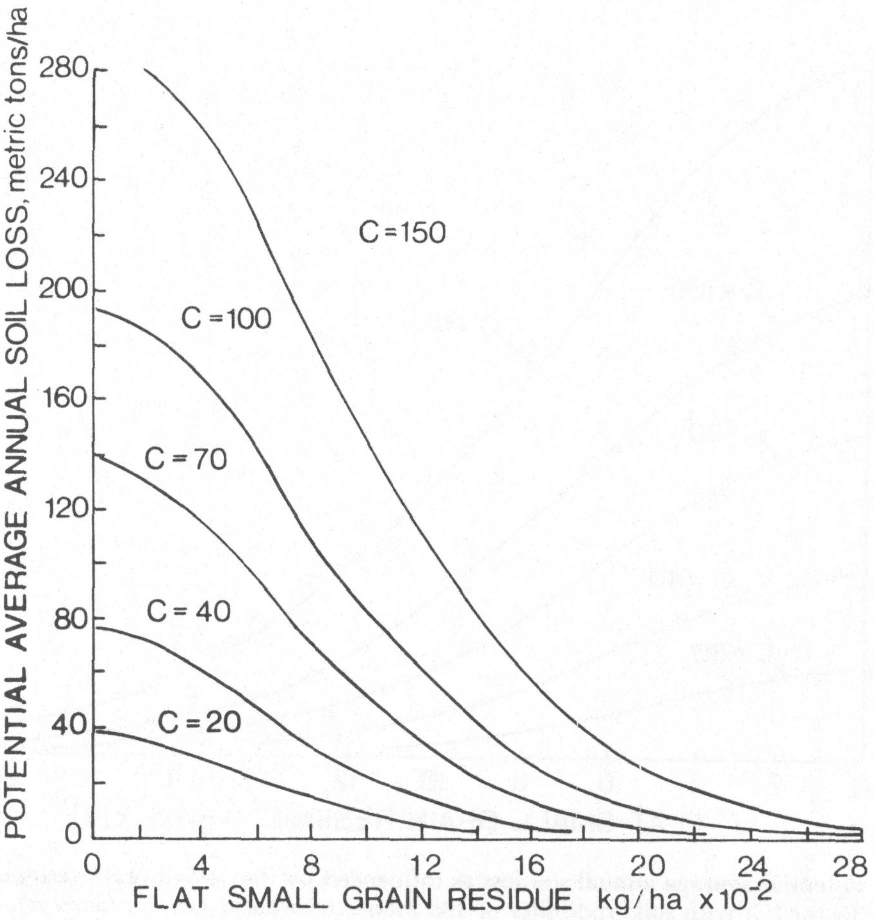

Fig. 4. Potential average annual soil loss as influenced by flat, small-grain residue and climatic factor (C) with soil erodibility of 193 metric tons/ha/yr (86 tons/acre/yr), WEG 3.

published data). Thus, the same amount of residue is produced from grain sorghum averaging 2,800 to 3,400 kg/ha. However, grain sorghum residue is not as effective as small grain residue for preventing wind erosion (Woodruff & Siddoway, 1973).

Craig and Turelle (1964) presented equivalent vegetative cover for several crops, including curves to convert quantity of various crop residues [peanuts (*Arachis hypogaea* L.), soybeans (*Glycine max* [L.] Merr.), shredded cotton (*Gossipium* sp.), guar (*Cyamopsis tetragonoloba* [L.] Taub.), sesame (*Sesamum indicum* L.), and standing cotton stalks] to quantity of equivalent flat, small-grain residue. Lyles and Allison (1976 Work Reporting Unit Progress Report) began comparing the effectiveness of crop residues—particularly soybeans, cotton, forage sorghum, silage corn—to that of flat, small-grain residue for protecting soil from wind erosion. Their results indicated that 2.6 and 3.9 times more soybean and cotton residues, respectively, than wheat residues are required to protect the soil when residues were similarly orientated in the fields. Woodruff et al. (1974) developed an equation to convert quantity of cattle feedlot manure to equivalent flat, small-grain residue for wind-erosion control.

The amount of residue on the surface at harvest decreases with time, type, and frequency of tilling. Greb and Black (1962) reported residue

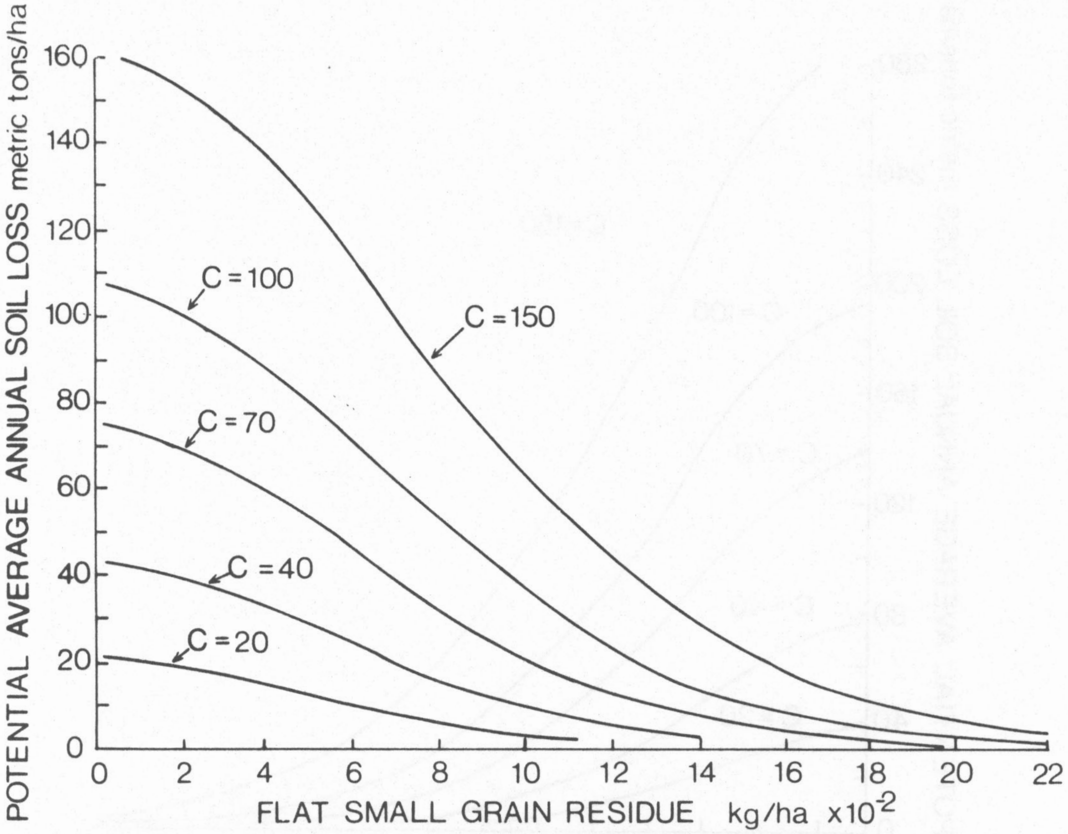

Fig. 5. Potential average annual soil loss as influenced by flat, small-grain residue and climatic factor (C) with soil erodibility of 108 metric tons/ha/yr (48 tons/acre/yr), WEG 6.

loses from climatic weathering and tillage burial. The weathering included losses from decomposition, wind, and possibly carbohydrate leaching. Undisturbed sorghum stubble lost 31 to 34% of its residue weight during winter weathering.

Post tillage to control weeds and prepare suitable seedbed for next planting reduces surface residue. Moldboard plowing completely buries all surface vegetation. The amount of residue left on the surface with tillage operations depends upon the initial amount of residue, stubble height, tillage tool used, method of operating, soil moisture, and previous tillage method (Anderson, 1953, 1961; Fenster, 1960; Fenster & McCalla, 1970; Greb & Black, 1962; Smika, 1976; Smika & Greb, 1975;

Table 2. Hectares of sands, loamy sands, and sandy loams on nonfederal rural lands (Kimberlin et al., 1976)

States	Sands	Loamy sands	Sandy loams
	million hectares		
Northeastern	0.6	1.3	7.6
Midwestern	8.1	8.4	13.1
Southern	14.9	17.0	31.1
Western	3.0	6.5	13.6
Total	26.5	33.3	65.5

Unger et al., 1971; Woodruff & Chepil, 1958; Woodruff et al., 1965). Greb et al. (1974) reported that, in a summer-fallow system in the Central Great Plains, most operators till fields from 4 to 6 times/season. By end of summer-fallow, subsurface tillage reduces residue by 50% (Black et al., 1974). Disk, chisel, and sweep tillage reduces residue about 50, 25, and 10% per operation, respectively (Fenster, 1960, 1975).

Various reduced and modified tillage systems have evolved with efforts to maintain residue on the surface (Fenster et al., 1973;[3] McCalla & Army, 1961; Russel, 1976; Zingg & Whitfield, 1957).

Chemical fallow (Black & Power, 1965) and eco-fallow (Fenster et al., 1973) systems using herbicides or herbicides and subsurface tillage during fallow conserve a large quantity of residue on the surface.

Directly seeding small grains into stubble without a fallow is being studied and shows promise. The advantages of this system as compared with tillage systems designed to preserve residues on the surface are: (i) the standing stubble is needed for erosion control only until the seeded crop produces enough cover to control erosion; (ii) standing stubble more effectively controls erosion than does an equal quantity of flattened residue; (iii) standing stubble, because it is not in direct contact with the soil, is less subject to decomposition than is stubble that has been tilled and mixed with the soil; and (iv) without tillage, the soil is not pulverized and the surface crust is left intact.

Table 3 shows some data from the above average production of dryland winter wheat, spring wheat, and barley (*Hordeum vulgare* L.) from sandy loam soils in northeastern Montana the fall of 1976. The standing stubble of the three small-grain crops should provide adequate protection through the winter and early spring months until a seeded crop takes over the protective function. Even the nonfertilized small grain provided adequate protection; however, the role of fertilizer in increasing plant populations and plant height is a positive erosion-control effect. In this no-till system, assuming adequate protection from the standing stubble, any straw residue (stems, leaves, head chaff, and awns) that went through the combine could theoretically have been used for animal feed or other purposes. From an average of all crops used in this example, about 2.5 metric tons/ha could be diverted to uses other than erosion control. However, the straw incorporated into the soil provides additional benefits.

Experiments (Black, 1973; Chepil, 1954; Siddoway, 1963) have shown that decomposing straw increased soil aggregation and decreased erodibility by wind. Siddoway (1963) found the increase in nonerodible aggregates attributed to straw residue tended to be greater when the residue was retained on the surface by sweep tillage than when it was turned under with the moldboard or mixed in the tillage layer with one-way disk. Black (1973) reported that each 1000 kg/ha of straw incorporated during a four-crop cycle reduced the erodible soil fraction about 8%. The erodible soil fraction was reduced to about half the original level with the highest rate (6730 kg/ha) of straw added.

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[3] Fenster, C. R., G. A. Wicks, and D. E. Smika. 1973. The role of eco-fallow for reducing energy requirements for crop production. Agronomy Abstracts 122, Am. Soc. of Agron., Madison, Wis.

Table 3. Measurements of small grain residues in northeastern Montana, 1976 (F. H. Siddoway, A. L. Black, and R. H. Ford, personal communication)

	Preharvest		Post harvest							
Crop† and nitrogen rate	Plant height	Total straw weight	Standing stubble height	Standing stubble population	Standing stubble weight	Loose straw weight	Loose ÷ standing (ratio)	Grain yield	Straw ÷ grain (ratio)	Standing stubble
	cm	kg/ha	cm	stalks/ha 10^{-6}	kg/ha	kg/ha		kg/ha		g/cm
Froid hard red winter wheat, no N	81	4,140	29	3.8	1,270	2,870	2.26	2,950	1.40	0.012
Froid hard red winter wheat, 68 kg N/ha	86	4,740	32	4.0	1,470	3,270	2.22	3,570	1.33	0.011
Fortuna hard red spring wheat, no N	89	3,680	29	3.6	1,320	2,360	1.79	2,760	1.33	0.013
Fortuna hard red spring wheat, 68 kg N/ha	99	5,830	30	5.5	1,910	3,920	2.05	3,680	1.59	0.012
Era hard red spring wheat (semidwarf), 40 kg N/ha	71	3,100	27	4.2	1,320	1,780	1.35	2,589	1.20	0.012
Hector spring barley, no N	61	2,240	16	3.6	640	1,600	2.50	2,230	1.00	0.011
Hector spring barley, 68 kg N/ha	71	4,240	16	6.6	1,020	3,220	3.16	3,810	1.10	0.010

† Winter wheat, 25-cm rows; spring grains, 18-cm rows.

POSSIBLE CONSEQUENCES OF RESIDUE REMOVAL ON WIND EROSION

Since a feasibility study is already in progress in Pratt County, Kans., for burning straw to produce electric power, we have chosen Pratt County as an example of residue removal.

Our calculations are based on the relationships of the wind-erosion equation (Woodruff & Siddoway, 1965). Surface soil texture in Pratt County, on which high-residue crops of wheat and sorghum are grown, ranges from loamy fine sands (WEG 2) to silt loams (WEG 6), with almost 40% of the cropland at WEG's of 2 and 3 (Horsch et al., 1968). We assumed fields were wide (erosion rate not affected by increase in field width); the climatic factor was 60 (Woodruff & Siddoway, 1965). The initial residue was produced by wheat of average yield in Pratt County. The 1975 Kansas Agricultural Report showed wheat yields of 1,750 kg/ha (26.0 bu/acre) and 1,430 kg/ha (21.3 bu/acre) for summer fallow and continual wheat, respectively. We assumed 2,800 kg/ha of wheat straw was produced. To calculate potential average annual soil loss from wind erosion, we considered the additional following conditions:

1) All residue removed from soil surface—either it was removed for alternative uses or plowed under.
2) Fifty percent of initial residue was removed. The remaining was further reduced 50% and flattened by conservation tillage, thus leaving 700 kg/ha.
3) Same conditions as in 2, except 50% of the residue was left standing.
4) Same conditions as in 2, except all of the remaining residue was maintained in the standing position.
5) Initial residue was reduced 50% from tillage and weathering.

The effect on potential average annual soil loss is shown for each of those conditions as a soil erodibility function of the soils in Pratt County (Fig. 6). The loamy fine sands and fine sandy loam soils with no residue will likely lose more than 100 metric tons/ha/yr. Even the fine-textured soils will lose more than 50 metric tons/ha/yr. However, if no residue is removed and fields are tilled so that 50% of the initial amount of residue still remains on the surface, even the highly erodible, coarse-textured soils should not erode.

When half of the residue is removed and the remaining half is flattened and further reduced 50% from tillage, wind erosion exceeds a tolerable amount on all soils. If half of the residue can be maintained upright (standing position), the finer textured soil would be adequately protected. Thus, if weeds were controlled chemically, after-harvest tillage were avoided, and all the stubble were standing, the wind erosion control would be adequate and approximately equal to stubble mulch tillage.

This example with wheat production demonstrates the necessity of using residue to control wind erosion. With appropriate management, a portion of the residue could possibly be removed with caution on the

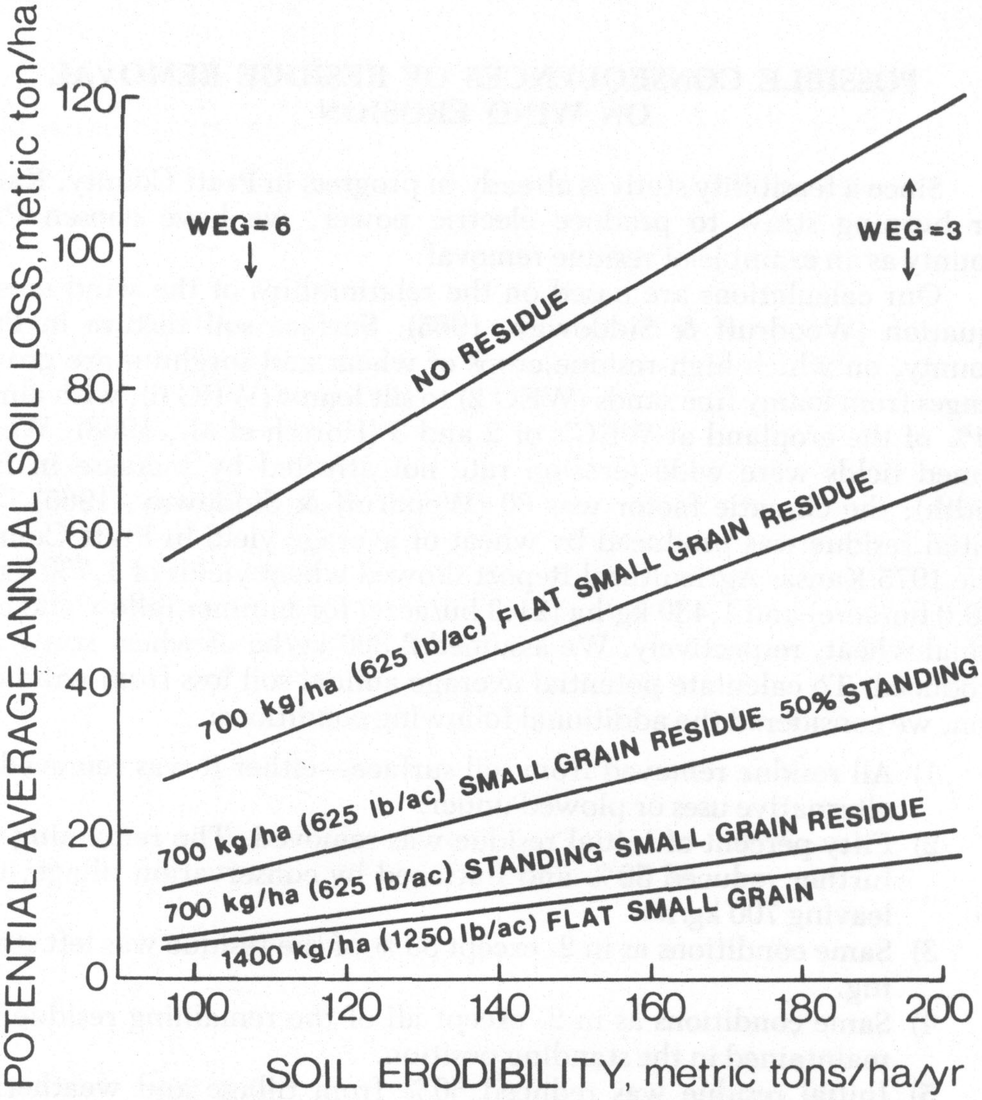

Fig. 6. Potential average annual soil loss as influenced by soil erodibility and amount of small grain residue. Calculated for smooth, wide fields and a climatic factor of 60.

finer textured soils without creating a serious wind-erosion hazard. Many farmers are not now adequately protecting their land from the ravages of wind and water erosion. Also, the amount of residue needed to protect the soil against wind erosion decreases as precipitation increases. However, the amount of residue needed to protect the soil against water erosion increases.

ALTERNATIVE METHODS TO CONTROL WIND EROSION

When residue is removed for feed, fuel, industrial use, or when little effective residue remains in the field after harvest, like with beans (*Phaseolus* spp.), sugar beets (*Beta vulgaris* L.), cotton, etc., other methods are needed to control wind erosion.

Stabilizers

Various soil stabilizers have been evaluated to find suitable materials and methods to control wind erosion (Armburst & Dickerson, 1971; Armbrust & Lyles, 1975; Chepil, 1955; Chepil et al., 1963a, b; Lyles et al., 1969; Lyles et al., 1974a). Several tested products successfully controlled wind erosion for short periods of time but were often expensive as compared with equally effective wheat straw anchored with a rolling disk packer (Chepil et al., 1963a). The following are criteria for surface soil stabilizers: (i) 100% of the soil surface must be covered, (ii) the stabilizer must not adversely affect plant growth or emergence, (iii) erosion must be prevented initially and reduced for at least 2 months, (iv) the stabilizer should apply easily and without special equipment, and (v) cost must be low enough for profitable use (Armbrust & Lyles, 1975). Armbrust and Lyles (1975) found five polymers and one resin-in-water emulsion that met all those requirements. However, they added that before soil stabilizers can be used on agricultural lands, methods must be developed to apply large volumes rapidly. Also, reliable preemergent weed-control chemicals for use on coarse-textured soils and films that resist raindrop impact, yet still allow water and plant penetration, must also be developed. The chemicals and films must not adversely affect the environment.

Nonvegetative mulches used for water conservation also can reduce wind erosion. These mulches include gravel (Chepil et al., 1963b; Corey & Kemper, 1968;[4] Fairbourn, 1973), coal (Fairbourn, 1974), water-repellent soil pellets (Fairbourn & Gardner, 1975), and aggresized clods (Hoyle et al., 1972).

Converting cattle feedlot manure to flat, small-grain equivalent residue also has been evaluated (Woodruff et al., 1974).

Field Length

Reducing the field width lowers the residue requirement to control wind erosion. As soil blows across an eroding field, amount of eroding soil increases until a maximum level is reached (Chepil, 1957). Therefore, barriers and/or strip-crops or another method that effectively stops erosion on the windward side of the field reduce erosion.

To demonstrate the reduced residue requirement with narrower fields, we calculated the amount of flat, small-grain residue required to limit the potential average annual soil loss to 11.2 metric tons/ha/yr (5 tons/acre/yr).

The hypothetical field is smooth with four levels of cloddiness. Values for I are 490, 300, 193, and 108 metric tons/ha/yr corresponding to wind erodible groups (WEG) of 1, 2, 3, and 6, respectively. The climatic and wind-erosion-direction factors are 100 and 1.5, respectively.

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[4] Corey, A. R., and W. D. Kemper. 1968. Conservation of soil water by gravel mulches. Hydrology Paper No. 30, Colorado State Univ., Fort Collins.

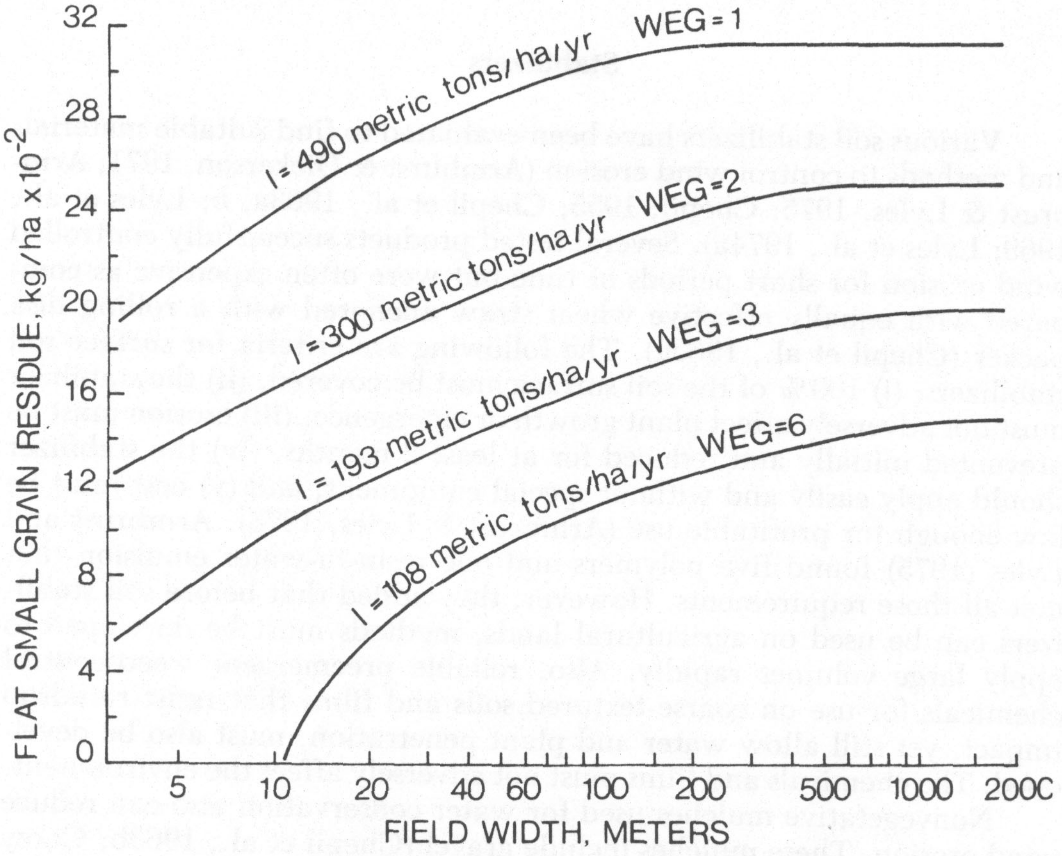

Fig. 7. Amount of flat, small-grain residue required to control potential average annual soil loss to 11.2 metric tons/ha (5 tons/acre) for the indicated erodibility (I) and field width. Climatic and wind erosion direction factors are 100 and 1.5, respectively.

The calculations (Fig. 7) showed that increasing field width beyond 300 m minimally affected erosion, especially on the highly erodible soils. As the width of the field decreases, its width influences residue requirement more. For example, when the field width decreases from 300 to 60 m, the flat, small-grain residue requirement (WEG 1) decreases from 3,140 to 2,910 kg/ha, but by further decreasing the field width 45 m, the residue requirement decreases to 2,480 kg/ha. This decrease is even more pronounced on lesser erodible soils, when WEG 6 fields with widths of 300, 60, and 15 m have residue requirements of 1,350; 1,000; and 450 kg/ha, respectively.

Wind Barriers

Barriers have long been recognized as valuable for controlling wind erosion (Bates, 1911). Recently (Hagen, 1976; Skidmore & Hagen, 1976), a model was presented which, when used with local wind data, showed wind-barrier effectiveness in reducing wind-erosion forces: (i) barriers reduced wind forces more than they did windspeed; (ii) a properly oriented barrier, when winds predominate from a single direction, will decrease wind-erosion forces by more than 50% from the barrier leeward to 20 times its height; and (iii) the decrease is greater for shorter distances from the barrier.

Different combinations of trees, shrubs, tall growing crops, and grasses can reduce wind erosion. Besides the more conventional tree windbreak (Ferber, 1969; Read, 1964; Woodruff et al., 1976), many other barrier systems are used to control wind erosion including annual crops like small grains, corn, sorghum, sudangrass [*Sorghum sudanese* (Piper) Stapf], sunflowers (*Helianthus annuus* L.) (Carreker, 1966; Fryrear, 1963, 1969; Hagen et al., 1972; Hoag & Geiszler, 1971), tall wheatgrass (*Agropyron* spp.) (Aase et al., 1976; Black & Siddoway, 1971), sugarcane (*Saccharum officinarum* L.), and rye (*Secale cereale* L.) strips on sands in Florida (J. D. Griffin, SCS Agronomist, personal communication, 1975).

However, most barrier systems for controlling wind erosion occupy space that could otherwise be used to produce crops. Perennial barriers grow slowly and are often established with difficulty (Dickerson et al., 1976; Woodruff et al., 1976). These barriers also compete with the crop for water and plant nutrients. Thus, the net effect for many tree barrier systems is that production may not be benefited from their use (Frank et al., 1977; McMartin et al., 1974; Skidmore et al., 1974; Skidmore et al., 1975; Staple & Lehane, 1955).

Although each method to control wind erosion has merit and application, establishing and maintaining vegetative cover, when feasible, remains the best defense against wind erosion.

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