24 Methods for Controlling Wind Erosion

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Wind erosion is a serious problem in portions of the USA and becomes more widespread and severe during droughts. Wind erosion can become a major problem whenever the soil is loose, dry, finely divided, bare or nearly bare, and the wind velocity exceeds the threshold velocity for the soil. Although wind erosion may occur in humid and subhumid climates, it is more prevalent in semiarid to arid areas and is extensive in the Great Plains.

In this report, we identify various practices used to reduce wind erosion and we describe their advantages and limits. Because of the tremendous variation in soils, climate, and crops across the USA, no single erosion control technique will be applicable to all areas. By combining two or more control techniques, however, wind erosion can be reduced to tolerable levels in most areas.

24-1 CONTROL METHODS

24-1.1 Surface Residues

The basic method of reducing wind erosion is to keep the soil protected with surface residues. While applicable to all areas, surface residues are more widely accepted in cropping areas where they do not cause planting or harvesting problems. Some residue is left in the field after harvest of most crops, but even high-residue crops may not produce sufficient residues to protect the soil when the erosion hazard is severe (Table 24-1). Of the 24 835 600 ha of cropland in the Great Plains, 42.2% will not be protected

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Table 24–1. Harvested area, and residues available on wide fields of barley, oats, corn, grain sorghum, and wheat† in the major land resource areas (MLRAs) of the Great Plains‡ (Skidmore et al., 1979).

MLRA	Barley		Oats		Corn		Sorhgum		Wheat		Total area	% not protected
	Harvested area	Residues available	Harvested area	Residues available	Harvested area	Residues available	Harvested area	Residues available	Harvested area	Residues available		
	kha	t/ha	kha	t/ha	kha	t/ha	kha	t/ha	kha	t/ha	kha	
52	245.1	−0.6	25.2	−0.5	0.1	−1.2	0	−4.2	803.9	−0.4	1074.3	100
53	148.5	0	223.5	0.1	43.7	−1.9	4.1	−2.1	1478.1	−0.8	1897.9	80
54	69.8	0.4	126.8	0.4	2.5	−1.5	0	−2.3	510.1	−0.6	709.2	72
55	577.3	0.4	455.8	0.6	234.7	−1.3	17.9	−1.2	2025.5	−0.3	3311.2	69
56	464.5	1.3	239.3	1.2	82.4	0.4	0	−3.0	1150.9	0.9	1937.1	0
57	38.6	2.2	90.8	2.2	32.5	1.9	0	−1.4	65.9	1.7	227.8	0
58	64.3	0.6	24.8	0.6	2.7	1.0	0	−3.5	182.8	0.7	274.6	0
59	54.9	0.3	26.2	0.3	0.5	0.2	0	−3.9	241.5	−0.1	323.1	75
60	5.5	−0.2	6.4	0.3	4.0	1.4	0.3	−2.0	25.2	0.4	41.4	14
61	2.6	−0.3	6.4	0	0.9	−0.5	0.2	−2.1	29.7	1.2	39.8	9
62	0.2	0	0.6	0.2	0.1	−0.4	0	−2.2	0.8	0.5	1.7	6
63	9.9	0	38.6	0	5.3	−1.0	18.7	−1.8	156.1	0.5	228.6	10
64	3.9	0.1	8.3	0.1	7.0	1.3	0.5	−2.0	49.0	0.8	68.7	1
65	2.2	0.2	10.4	−0.2	99.2	2.1	2.0	−1.4	17.5	0.6	129.5	8
66	9.2	0.2	36.1	0.7	32.8	−1.2	14.9	−1.3	30.8	1.0	123.8	39
67	27.2	0	13.0	−0.4	113.7	1.9	46.0	−2.4	747.5	−0.3	947.4	85
68	4.6	0.9	0	−2.8	28.6	2.6	0.4	−1.7	74.6	−0.5	108.2	69
69	4.5	0.5	0.7	−0.3	14.5	1.9	42.7	−1.6	147.3	−0.8	209.7	91
70	0.9	−0.7	0	−3.4	4.6	0	15.2	−3.3	30.2	−1.0	50.9	100
71	1.2	0.5	5.9	0.6	318.0	2.8	23.7	−0.7	58.4	1.9	407.2	6
72	5.9	−0.4	4.5	−0.7	464.6	2.0	205.4	−1.2	1728.9	0	2409.3	9
73	1.9	0.3	7.2	0.3	144.5	2.6	285.5	−1.0	869.6	1.0	1308.7	22
74	0.6	1.0	5.5	0.6	14.5	1.3	112.6	−0.1	302.1	1.9	435.3	26
75	2.4	1.3	22.8	1.3	568.1	3.5	602.4	0.3	715.8	2.2	1911.5	0
76	4.4	1.6	11.5	1.0	29.4	0.9	190.9	0.4	200.4	2.2	436.6	0
77	12.1	0.4	4.4	−0.7	280.5	2.8	1287.3	−0.7	1144.5	−0.9	2728.8	89
78	29.9	−0.4	66.4	−0.3	1.2	2.0	297.9	−1.5	1196.3	0	1591.7	25
79	1.9	0.3	1.2	−0.3	18.8	2.8	89.9	−1.1	439.2	0.8	551.0	17
80	36.7	1.0	34.1	0.8	4.2	2.3	77.2	−0.2	1198.4	1.9	1350.6	6

† All wheat (spring, winter, durum). ‡ T (Tolerable soil loss) = 11.2 t ha^{-1} yr^{-1} (5.0 t $acre^{-1}$ yr^{-1}); K′ (soil ridge roughness factor) = 1.0.

from wind erosion with residue from the five "residue crops" listed. In major land resource areas 52 (north-central Montana) and 70 (eastern New Mexico), none of these crops will produce sufficient residue to protect the soils. Areas that do not produce enough residue to protect the soil surface are concentrated along the western boundary of the Great Plains, which coincides with areas of limited rainfall and high winds.

24-1.1.1 Crop Residues

Dr. J. D. Bilbro (unpublished data, 1984) revealed that winter wheat (*Triticum aestivum* L.) at Big Spring, TX, will produce no residue 30% of the time and estimated erosion will be 39 t ha^{-1} yr^{-1} 50% of the time. The quantities of various crop residues needed to protect soils from wind erosion have been determined (Chepil, 1944; Chepil et al., 1963; Siddoway et al., 1965; Skidmore and Siddoway, 1978) and compared to an equivalent amount of flat small grain (Lyles and Allison, 1980 and 1981) (Fig. 24-1).

Standing residues are more effective than flattened residues (Chepil et al., 1963), and rows of crop residue perpendicular to wind direction control

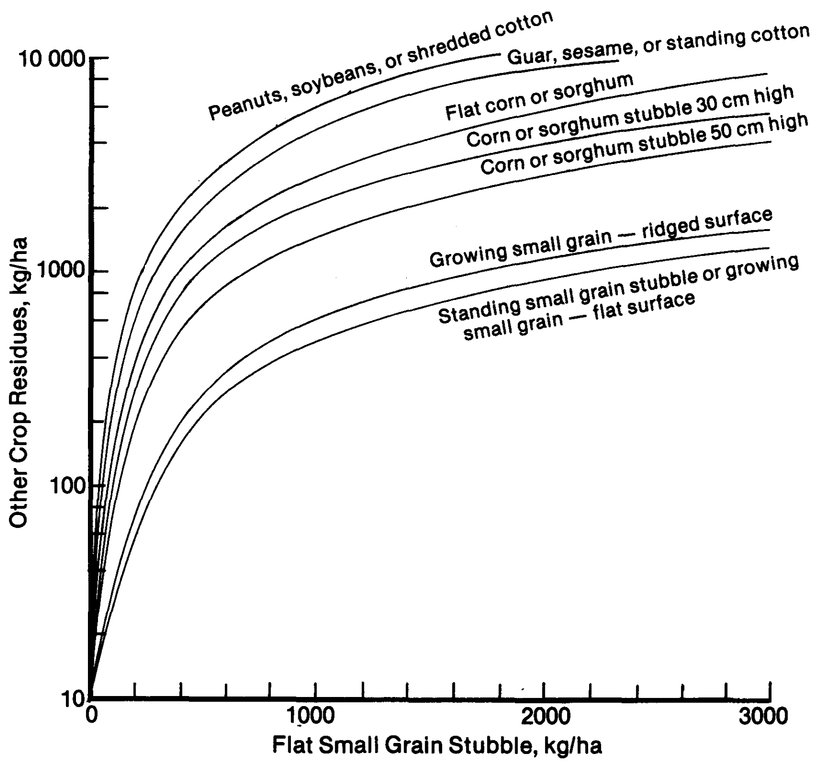

Fig. 24-1. Amount of residue of various crops needed to equal a given amount of flat small grain stubble (USDA-SCS, 1973, Chart #3).

wind erosion more effectively than parallel rows (Englehorn et al., 1952; Skidmore et al., 1966; Lyles et al., 1973). With Lyles and Allison's (1976) model of standing crop residues, if dimensions of residues are known, the estimated erosion can be calculated for any soil. The relationships are for smooth, leaf-free residues and do not consider possible branching.

24-1.1.2 Stubble-Mulch Tillage Practices

The goals of stubble-mulch tillage are to reduce the number of tillage operations and maintain residues on the soil surface for conserving water and controlling erosion. The advent of stubble-mulch, sweep-tillage machines in the late 1930s made possible the control of weeds without destroying the protection provided by the stubble. Woodruff et al. (1965 and 1972) have shown that large sweeps reduce residue levels of small grains about 10% and disc implements about 50% (Table 24-2). The moldboard plow usually buries all residues. The amount of residue buried with tillage implements depends on soil conditions, operating speed, proper clearance (0.6 m), and flexibility of adjustment and implement frame. In recent years field size, tractor horsepower, implement size, and operating speed have all increased, which generally reduces the amount of residues on the soil surface.

As surface residues are exposed to weathering and deterioration, their weight decreases. This does not necessarily mean, however, that the protection provided will decrease in proportion to the weight change. The relationship between physical properties of the residue and erosion was modeled by Lyles and Allison (1976). Erosion control should remain constant if the orientation of the residue or its physical dimensions do not change with time. Using stalk densities of 1.57 and 1.37 kg/m^2 and stalk diameters of 2.78 and 17.7 mm for wheat and sorghum (*Sorghum vulgare*), respectively, Lyles and Allison (1976) showed that the weight required to

Table 24-2. Tillage machine and percentage of surface residue lost with each operation (Woodruff et al., 1972).

Tillage machine	Residue lost
	%
Stirring or mixing machines:	
One-way disk (0.60- to 0.66-m disks)	50
One-way disk (0.46- to 0.56-m disks)	40
Tandem or offset disks	50
Power disk	60
Field cultivator (0.41- to 0.46-m sweeps)	20
Chisel plow (50-mm chisels 0.3 m apart)	25
Mulch treader (spade-tooth)	25
Mulch treader (spike-tooth)	30
Sidewinder rotary tiller (0.30-m tilled on 1-m center)	30
Subsurface machines:	
Blades (0.91 m or wider)	10
Sweeps (0.60 to 0.91 m)	15
Rodweeders (plain rod)	10
Rodweeders (with semichisels or shovels)	15

completely cover the soil surface compared well with values reported by Fryrear and Koshi (1971) (Fig. 24–2). We believe that the percentage of the soil surface covered is easier to estimate in the field than is the weight of residues on the soil surface and that the former will be related to wind erosion. Erbach (1982) used the percentage of soil surface covered by residues to evaluate residue reduction with various tillage systems. The percentage of soil cover can be measured by the meter-stick method (Hartwig and Laflen, 1978).

24–1.1.3 Permanent Vegetation

Permanent vegetation is the ultimate means of protecting soils from wind erosion. Properly managed grasses are the most reliable method of reducing erosion on deep sandy soils. But, if the grass is overgrazed, erosion can be very severe, particularly during prolonged droughts (Lyles, 1980). One advantage of grasses is that the plant crowns and root systems provide some cover even as erosion becomes severe.

24–1.1.4 Limits of Application

The basic method of protecting the soil with crop residues is universally applicable, but farmer acceptance depends on short-term economics. Farmers growing high residue crops may be more receptive of advances in stubble mulching than those that must switch from a high-value crop to a

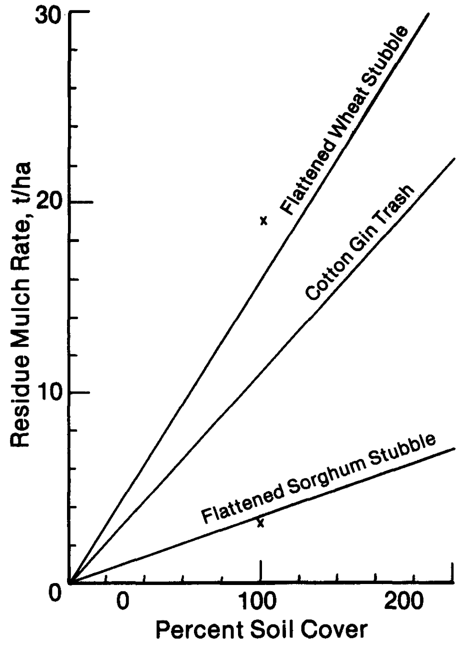

Fig. 24–2. Percentage of soil surface covered with sorghum, cotton gin trash, and wheat mulches (Fryrear and Koshi, 1971, Fig. 2). X indicates values calculated from Lyles and Allison (1976).

residue crop. Residues do reduce evaporation losses from soils, thus conserving soil water. On the minus side, residues intercept herbicides, and their use may require a modification of weed control practices. Residues also break down with time, and little residue may remain on the soil surface during prolonged droughts. To control wind erosion as surface residues deteriorate, some other practice, such as barriers or tillage, must be used until more residues are produced.

Gross income in semiarid areas is usually greater from cultivated crops than from grassland. Many fields replanted to grass during or immediately following a drought are plowed again as favorable rainfall and higher crop prices return. But, improvements in grass-establishment techniques and production in semiarid regions and improved cattle prices could reverse this economic situation.

24–1.2 Reducing Field Width

Wind erosion increases with the length of the eroding surface until some maximum is reached. The relation of distance to maximum erosion flux and soil type is shown in Table 24–3 (Chepil, 1957). The values in the table are for a wind blowing perpendicular to the strip at a velocity of 17.8 m/s at 15 m above the ground. The width of field strips required to control erosion decreases as wind velocities increase or the wind direction approaches parallel to the strip. Reducing field width is most effective when all erosive winds are from the same direction (Skidmore and Woodruff, 1968). Although the distinction between crop barriers and crop strips has not been defined, in this report nonerodible strips less than 3 rows wide (usually about 1 m) will be called crop barriers and will include tree shelterbelts; strips wider than 3 rows will be called crop strips.

Table 24–3. Average distance for soil flux to reach maximum and width of field strips required to control erosion from a 17-m/s wind at 15 m above the ground blowing perpendicular to strip and 0.3-m high stubble on windward side of eroding area (Chepil, 1957, Table 1).

Soil	Distance†	Field strip‡
	m	
Sand	30	6
Loamy sand	51	8
Silty clay loam	219	25
Granulated clay	280	30
Clay loam	419	45
Sandy loam	719	76
Silty clay	811	86
Loam	1006	105
Silt loam	1289	131

† Average distance for soil erosion to reach a maximum.
‡ Average width of field strip required to keep average soil flux below 0.01 kg m^{-1} width s^{-1}.

24-1.2.1 Crop Strips

Strip cropping, using alternate strips of small grains, corn (*Zea mays* L.), or sorghum with a fallow strip, has been used for years on erodible soils in the Northern and Central Great Plains to reduce wind erosion (Chepil, 1957). It has been very successful in these areas because of the prevailing direction of erosive winds. The widths of the fallow and crop strips are usually equal and are determined by even units of machinery widths. For all soil textures except a loam or silt loam, the strips must be less than 100 m wide to completely protect the soil from wind erosion (Table 24-3).

24-1.2.2 Shelterbelts and Crop Barriers

Trees or tall vegetation have been used to shelter soils in Russia, China, central Texas, south-central Kansas, and eastern Montana for many years, and basic principles of shelterbelt designs have been documented (Black and Siddoway, 1971; Fryrear, 1963; Denisov, 1960; Sheng and Kang, 1961; and Great Plains Agriculture Council, 1976). The higher the wind velocity, the smaller the protected zone, but Hagen (1976, p. 31) reported that "maximum wind and erosion reduction extends over a larger leeward area when windbreak porosity is near 40% as compared with a less-porous windbreak." Erosion can be reduced appreciably to the lee of barriers with moderate reductions in wind velocities (Fig. 24-3). Because of the funneling

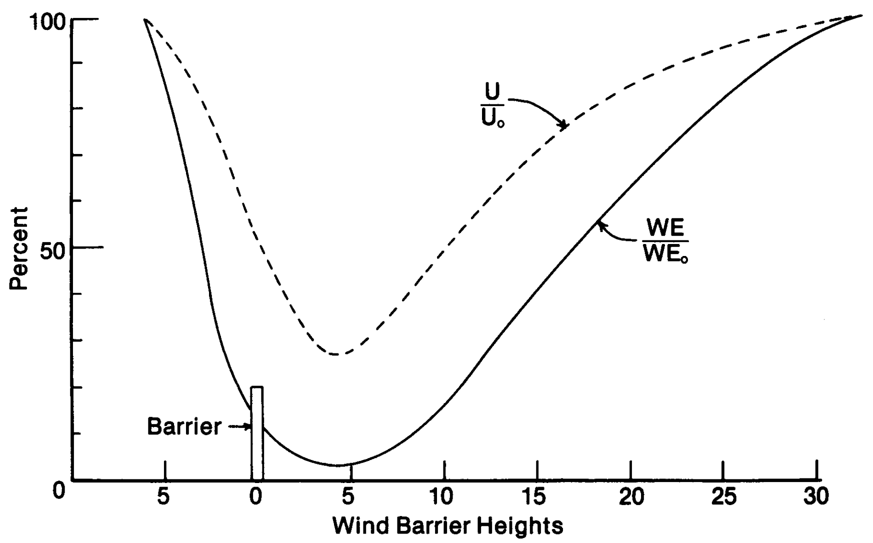

Fig. 24-3. Ratio of shelter to open field wind speed (U/U_0) and wind erosion (WE/WE_0) with all windspeeds above threshold velocity and normal to a 40% porous windbreak. Wind speeds measured at 0.12H above soil surface (Hagen, 1976, Fig. 2).

effect created by a gap in the barrier, 2-row barriers are usually recommended to minimize gaps (Hagen et al., 1972).

Historically, perennial barriers have been grown where they can trap drifting snow to help provide sufficient water for their growth. In hot and arid climates, and in the absence of a water table, the roots of the barrier must move a lateral distance about 2.5 to 3 times the height of the barrier (Greb and Black, 1961). Unless the barrier produces a harvestable crop, it removes an appreciable area of cropland from production. In more arid areas, annual crop barriers or grass strips are used because of less competition for soil moisture, but the annual crops must be established each year. Because of different growth habits, trees or crops will protect different distances leeward, but the usual distance is considered to be 10 times the height of the barrier (Table 24–4).

24–1.2.3 Field Orientation

Reducing the width of a field or installing shelterbelts or crop strips will not be effective unless the field is oriented perpendicular to the prevailing erosive wind direction. Skidmore and Woodruff (1968) have prepared tables showing the prevailing direction of erosive winds during different months of the year for the USA. With a high proponderance value, field width can be reduced with strips or shelterbelts to effectively reduce wind erosion. With low preponderance values, orientation against the wind is less effective.

24–1.2.4 Interplanting

In some vegetable-producing areas of the Midwest, rows of a protective crop are planted in conjunction with a crop sensitive to wind damage. While

Table 24–4. Leeward distance protected by various shelterbelt trees or annual crop barriers (Woodruff et al., 1972).

Windbreak	Factors for determining protected distances†
Trees and shrubs‡	
2-row (mulberry)	18.2
5-row (plum, cedar, mulberry, elm, olive)	15.0
1-row (Osage orange)	12.0
3-row [cedar (2), shrub]	11.0
1-row (Siberian elm)	9.5
Annual crops	
Kochia	12.0
Sudangrass	7.5
Grain sorghum	6.0
Forage sorghum	4.0
Broomcorn	1.0

† To find the distance protected, multiply barrier height by the appropriate number in the right-hand column.

‡ Mulberry (*Morus alba* f. *tartarica*), plum (*Prunus americana*), cedar (*Duniperus virginiana*), elm (*Ulmus pumila*), olive (*Elaegnus angustifolia*), osage orange (*Macolura pomifera*).

the practice can be very effective, it requires a high level of management. This practice is usually limited to areas where water stress on the cash crop is not a problem.

24-1.2.4 Limits

Shelterbelts, crop strips, or crop barriers are very effective in reducing erosion in areas with a dominant prevailing wind direction during the wind erosion period. Most trees or shrubs require several years before they attain their design height, and the establishment of trees in semiarid regions is difficult. Because trees must live on available rainfall during prolonged droughts, mortality within the shelterbelt can be a problem. The sheltered area provides homes for wildlife and may improve the microclimate for adjacent crops, but it can also harbor nonbeneficial insects. In warm, semiarid areas the perennial barrier must extend its root system laterally to survive and thus competes with the cash crop for soil water and nutrients.

24-1.3 Soil Roughness, Clods, and Stabilizers

Next to residues, surface roughness and clods are the most widely used methods of reducing wind erosion. Although clods are temporary, they can be re-formed in cohesive soils. They are most effective when used in combination with residues and field orientation but require careful management to optimize benefits. The interaction between soil texture, tillage method, cloddiness, and crop yields must be recognized. No tillage method can effectively reduce wind erosion of a deep sand that contains no silt or clay.

24-1.3.1 Tillage and Clods

Clods are the result of proper tillage performed at the most appropriate time and soil moisture content. They are desirable for wind erosion control, but large clods are not desirable for a good seedbed. The lister and moldboard plow produce the highest number and most stable clods (Lyles and Woodruff, 1962). These are the dominant tillage implements used to reduce wind erosion in the Southern Plains on coarse textured soils with no residue. Fryrear (1980) found a positive relation between tillage methods that leave a cloddy soil surface and cotton yields on an Amarillo fine sandy loam soil (fine-loamy, mixed, thermic, Aridic Paleustalfs). The increased cloddiness from listing or moldboard plowing was evident for 12 months. Clods are usually stable in the absence of rainfall or freezing and thawing. Intense rainstorms will melt down clods, particularly on coarse-textured soils, but, if soils are tilled soon after a rain, more clods can be formed (Fryrear, 1980). The key is timeliness of the tillage operation. Although tilling a wet soil increases the hazards of soil compaction, the potential wind erosion hazard on coarse-textured sandy soils is great enough to justify the practice.

24-1.3.2 Soil Roughness

In addition to leaving clods on the soil surface, listing effectively roughens the soil by creating ridges and furrows. Soil ridges alone can reduce erosion 50 to 90% (Armbrust et al., 1964; D. W. Fryrear, unpublished data, 1984). For soil ridges to be most effective, they must have erosion-resistant soil clods on the surface. If a cloddy ridge surface results from listing, wind erosion will be controlled until the clods are broken down by additional tillage, weathering, or erosion. Tillage to reduce wind erosion will be more effective where residue crops or crops with extensive root systems are grown that will increase or maintain soil organic matter. Decomposing surface residues improve cloddiness and stability of the clods (Chepil, 1955b). Tillage also may be used to roughen the soil and reduce the hazard of wind erosion when the wind is parallel to shelterbelts or crop strips, or while shelterbelts are being established.

24-1.3.3 Soil Stabilizers

Chemicals for stabilizing soil surfaces against wind erosion have been evaluated (Armbrust and Dickerson, 1971; Armbrust and Lyles, 1975; Chepil, 1955a; Chepil and Woodruff, 1963; Chepil et al., 1963; Lyles et al., 1969; Lyles et al., 1974a). Several products successfully controlled wind erosion for a short time, but many were more expensive than equally effective wheat straw anchored with a rolling disk packer (Chepil et al., 1963). Armbrust and Lyles (1975) found five polymers and one resin-in-water emulsion that reduced erosion for two months, did not adversely affect plant emergence or growth, and were easily applied without special equipment. They added, however, 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 coarse-textured soils must be developed, as well as films that are resistant to raindrop impact yet allow water and plant penetration and are environmentally safe.

24-1.3.4 Emergency Tillage

When soil surface residues are depleted and a wind erosion hazard exists, emergency tillage is often the last resort (Woodruff et al., 1957). The use and type of emergency tillage varies with locality and climatic condition. While listing or chiseling in midwinter in the Central or Northern Great Plains may be considered emergency tillage, listing is the dominant control method in the Southern Great Plains and is not normally considered emergency tillage. If surface clods on listed sandy soils are broken down by rainfall, a sand fighter or rotary hoe is used to disturb the soil and leave new clods on the surface. The sand fighter and rotary hoe could be considered emergency tillage implements since they are used to control wind erosion, but they are not effective if the soil has been blowing and the surface few millimeters of soil is dry.

If winter wheat does not protect soil from blowing, the field must be roughened to reduce wind erosion. A chisel is used because it destroys less wheat and takes less horsepower than a lister. A spacing of 0.60 to 0.80 m between narrow-point chisels is most effective when operated just deep enough to bring clods to the surface and at a speed of at least 1.8 m/s. Chiseling on 0.76-m spacing did not reduce winter wheat yields in Kansas (Lyles and Tatarko, 1982). All emergency tillage operations should be done perpendicular to the wind direction (Woodruff et al., 1972).

24-1.3.5 Limits

Clods are compact, coherent masses of soil formed by tilling the soil. To effectively reduce wind erosion, most of the soil surface must be covered with nonerodible clods. This is possible for most soils if they are properly tilled before wind erosion begins. Generally, the finer the soil texture the greater the number and stability of clods formed. Coarse-textured soils must be tilled after each rain to bury loose sand grains and bring more clods to the surface. Because most crops are seeded in the surface 0.05 m of soil, the farmer must compromise to have the minimum clods to control wind erosion and still have a satisfactory seedbed.

24-2 INTEGRATED CONTROL METHODS

Wind erosion is a problem on a wide variety of soils, climatic regions, and crop conditions, and maximum control may require the use of several measures. While we cannot describe all possible combinations, we discuss the basic ones.

24-2.1 Residue and Tillage

Adequate surface residues are the major control method, but in semiarid regions residue crops may not produce sufficient cover to protect the soil. In semiarid areas and during drought periods in all areas, tillage may be necessary to reduce wind erosion. An Amarillo fine sandy loam has a potential soil loss in excess of 100 t ha^{-1} yr^{-1}, but tilling this soil and applying gin trash to the surface reduces soil loss below the assumed tolerable loss of 11 t ha^{-1} yr^{-1} (Fryrear and Koshi, 1971).

Winter wheat is often too small in midwinter to protect erodible soils from wind erosion. If the wheat fields start to erode, farmers use emergency tillage to roughen the soil. This combination of growing wheat and tillage can be very effective if tillage is done before erosion becomes excessive.

24-2.2 Field Width, Residues, and Tillage

When permanent barriers, such as shelterbelts or perennial plants are being established, adequate surface residues and/or tillage must be used to control wind erosion. As the barrier attains its design height, the quantity of surface residue needed to protect the soil can be reduced and lower residue-producing crops grown. An alternative is to use a more intensive tillage program to reduce wind erosion during barrier establishment. Because barriers are usually oriented perpendicular to the prevailing wind, soil ridges can control wind erosion very effectively.

24-3 OPTIMUM CONTROL PERIODS

24-3.1 Soil Damage

The objective of practices to control wind erosion is to reduce erosion below the soil loss tolerance established for a particular soil. Chepil (1960) described the visible effects of wind erosion for various levels of annual soil loss (Table 24-5). It is difficult or even impossible to visually detect wind erosion losses of less than 41 t ha^{-1} yr^{-1}. If we assume that wind erosion damages soils when surface soil is removed from the land, then we are concerned with the removal of soil fines, primarily silt, clay, and very fine sands. These fractions of soil are responsible for holding water and nutrients within the root zone and for maintaining good soil tilth. The resultant short-term impact on soil productivity depends on soil depth, but the long-term impact is basically an accelerating deterioration in productivity. Since more erosion occurs within a few months each year, efforts to control wind erosion should be concentrated during these months to be most effective. The specific time varies, but at Big Spring, TX, 75% of the dust storms occur during January through May, and 50% occur in February, March, and April (Fryrear, 1981).

24-3.2 Plant Damage

Field and wind-tunnel tests have established the relative tolerance of various crops to blowing sand (Table 24-6) (Fryrear et al., 1975). Some plants, such as onions (*Allium cepa*), may not be killed, but their growth is delayed several weeks and yields are significantly reduced. For most crops, tolerable soil loss is less than the assumed tolerable loss that will ensure continued productivity. In the Southern Great Plains, farmers recognize the need to control wind erosion during the critical planting and crop establishment period. As crops emerge, the soil surface is roughened after each rain. As crops mature they become more tolerant to wind erosion damage, and the wind erosion hazard decreases.

While blowing sand before harvest would have little effect on the yield or sorghum or wheat, it would reduce the marketability of leaf crops such as tobacco (*Nicotiana tabacum*), cabbage (*Brassiea oleracea*), or lettuce (*Lactuca sativa*) (Armbrust, 1979; Downes et al., 1977). Though shelter-

Table 24–5. Relationships among quantity of wind erosion and visible effects of erosion (Chepil, 1960, Table 3).

Degree of erosion	Description of erosion	Annual soil loss†
		t/ha
None to insignificant	No distinct visible effects of soil movement.	>41
Slight	Soil movement not sufficient to kill winter wheat in boot stage.	41–136
Moderate	Removal and associated accumulations to about 25 mm depth sufficient to kill wheat in boot stage.	136–454
High	About 25–50 mm removal and associated accumulations.	454–906
Very high	50–75 mm removal with small dune formations.	906–1360
Exceedingly high	More than 75 mm removal with appreciable piling into drifts or dunes.	>1360

† Occurring in the vicinity of Garden City, KS, during 1954 through 1956.

Table 24–6. Crop survival as influenced by duration of exposure to a 15 m/s wind with sand flux of 0.05 kg m^{-1} width s^{-1} on plants 9 or 10 days old (Fryrear and Downes, 1975, Table 3).

	Survival rates at three exposure times (min)		
Crop	5	10	20
	%		
Pepper	75	8	0
Onion	100	100	100
Cabbage	100	87	56
Southern pea	100	94	72
Carrot	91	10	4
Cucumber	100	100	46
Cotton	100	85	15
Sunflower	91	88	72
Avg.	95	72	46

belts, crop barriers, or crop strips help reduce erosion damage, many farmers roughen the soil as soon as possible following a rain while the crop is small.

24–4 SUMMARY

Properly managed crop residues can effectively reduce wind erosion wherever they are normally grown. In areas with insufficient residues to protect the soil, proper tillage can greatly reduce the erodibility of cultivatable sandy soils. Timing of the tillage operation is extremely important to produce the combination of surface clods and roughness needed to control wind erosion. When winter cover crops do not protect the soil surface, tillage is used as an emergency wind erosion control practice. Crop strips, crop barriers, or shelterbelts reduce field width and erosion from perpendicular winds. Principles of conservation tillage can supplement the barrier's influence, and tillage is essential as the barriers are being established.

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