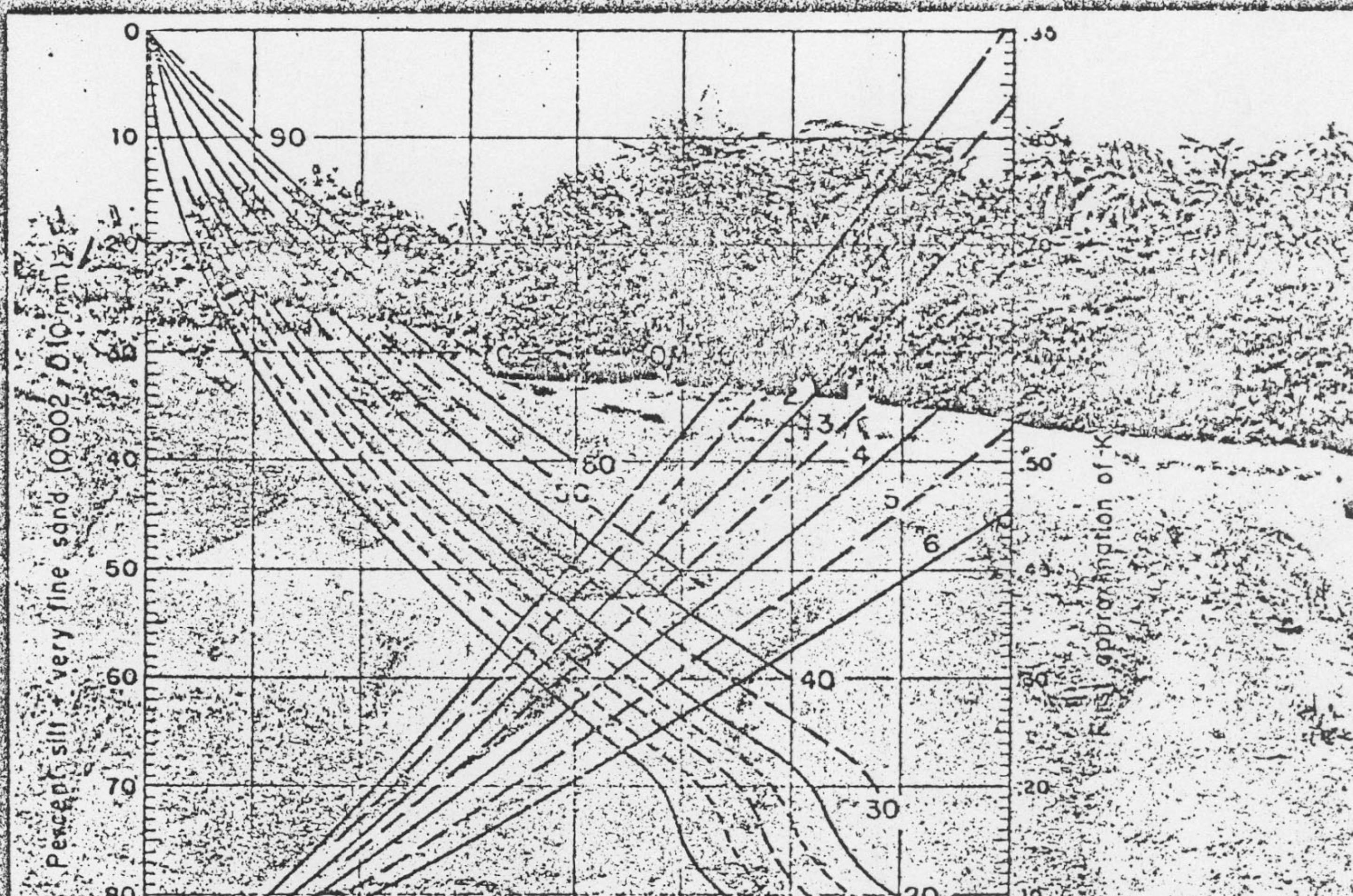
FAO SOILS BULLETIN 34

assessing soil degradation



FOOD AND AGRICULTURE ORGANIZATION
OF THE UNITED NATIONS ROME

ANNEX VI

CRITERIA FOR ASSESSING WIND EROSION 1/

by E.L. Skidmore

1. INTRODUCTION

Wind erosion is serious in many parts of the world. General areas most susceptible to wind erosion on agricultural land include much of North Africa and the Near East, parts of southern and eastern Asia, Australia and southern South America, and the semi-arid and arid portions of North America (FAO, 1960). In addition, such agricultural areas as the Siberian Plain and others in the USSR are potentially susceptible to wind erosion.

Soil erosion by wind, generally thought to be limited to semi-arid and arid areas, can be a problem wherever: 1) the soil is loose, dry, and reasonably finely divided; 2) the soil surface is smooth and vegetative cover is absent or sparse; 3) the field is large; and 4) the wind is sufficiently strong to move soil. These conditions are likely to prevail in semi-arid and arid areas, where precipitation is inadequate or where the climatic vagaries from season to season or year to year prevent maintaining crops or residue cover on the land; however, they sometimes exist in subhumid and even humid areas.

Wind erosion damages in several ways. It physically removes from the field the most fertile portion of the soil, thereby lowering productivity (Daniel and Langham, 1936; Lyles, 1975). Some eroded soil enters the atmospheric dustload (Hagen and Woodruff, 1973), which obscures visibility, pollutes the air, causes traffic hazards, fouls machinery, and imperils animal and human health. Blowing soil also fills road ditches and irrigation canals, reduces seedling survival and growth, lowers the marketability of many vegetable crops, and increases the susceptibility of plants to disease and to the transmission of some plant diseases.

This paper presents criteria for assessing wind erosion on a regional basis by first assessing it on a field basis. Also, the regional wind erosion hazard can be evaluated based on the erodibility of the soil and meteorological conditions conducive to soil detachment and transport.

2. ASSESSING WIND EROSION ON A FIELD BASIS

Studies to understand the mechanics of the wind erosion process to identify major factors influencing wind erosion, and to develop wind erosion control methods led to the development of a wind erosion equation (Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965). The equation was designed to determine the average potential erosion from a particular field and the field conditions necessary to reduce potential erosion to a specified amount.

1/ Contribution from the Agricultural Research Service, U.S. Department of Agriculture, in cooperation with the Kansas Agricultural Experiment Station. Dept. of Agronomy Contribution No. 1647-a.

It is assumed that the reader is familiar with the wind erosion equation, therefore, only a brief description will be given here. More detail has been given by Chepil and Woodruff, 1963; Woodruff and Siddoway, 1965; Skidmore and Woodruff, 1968; Skidmore et al., 1970; Skidmore, 1976.

The general functional relationship between the dependent variable, E (the potential average annual soil loss in tons per hectare), and the independent variables is: E = f (I, K, C, L, V), where I is a soil erodibility index; K is a soil-ridge roughness factor; C is a climatic factor; L is field length along the prevailing wind erosion direction; and V is equivalent quantity of vegetative cover.

Relations among variables are complex, and a single equation that expresses E as a function of the independent variables has not been devised. The equation was solved in a stepwise procedure involving graphical solutions until a computer solution was developed to simplify the procedure (Fisher and Skidmore, 1970; Skidmore et al., 1970).

The solution of the wind erosion equation gives the amount of erosion expected, in tons/ha/year, from a given agricultural field.

The information needed to assess potential soil loss from a field is: (1) percentage of soil aggregates exceeding 0.84 mm; (2) length and steepness of windward knoll slopes; (3) ridge height and spacing; (4) climatic factor; (5) angle of deviation of prevailing wind erosion direction from right angles to field strip; (6) preponderance of wind erosion forces in prevailing wind erosion direction; (7) height of wind barrier, if any; (8) field width; (9) quantity of vegetative cover; and (10) type of vegetative cover. Information for items 4 and 6 and for determining item 5 can be obtained by month for many USA locations from the literature (Skidmore and Woodruff, 1968). The percentage of soil aggregates exceeding 0.84 mm (item 1) can best be obtained by dry sieving; however, in practice, the percentage is often determined from wind erodibility groups based on soil type or predominant soil textural class (Hayes, 1972). Other factors can be measured in the field or estimated by comparing field conditions with similar field conditions for which the factors have been measured.

3. ASSESSING WIND EROSION ON A COUNTY AND REGIONAL BASIS

The wind erosion equation can be used as a basis for assessing wind erosion on an area, such as a county, larger than an individual field.

In the USA, pertinent data can be obtained from several sources. Anual area cropped and yield data for each major crop are available by county from "Agricultural Statistics", published by state boards of agriculture. Total land area by county is available from the Conservation Needs Inventory; soil data are available from soil surveys; and climatological data are available from the National Climatological Record Center. Using those data and the wind erosion equation, one can estimate potential average annual soil loss for a county or a group of counties.

Consider Ellis County, Kansas, for example. Table 1 gives the major soils in the county, the areal extent of those soils, their approximate erodibility based on soil textural classification, and an estimate of the average annual potential soil loss from each of the soils. For this calculation, it was assumed that the field is wide, smooth and bare of vegetation. The grain yield of major crops was estimated from the average county yield of that crop, multiplied by a factor that compares the estimated capability of a particular soil with other soils in the county to produce a given crop. The straw or stover was estimated from grain yield. On the average, winter wheat produced 1.7 quintals of straw for each quintal of grain. Sorghum and maize produced about equal grain and stover.

Table 1 STRAW RESIDUE PRODUCED ON THE VARIOUS SOILS IN ELLIS COUNTY, KANSAS, AND AMOUNT OF STRAW NEEDED ON THE SOIL TO CONTROL WIND EROSION TO 11.2 t/ha/yr

SOIL	AREA	ERODIBILITY	SOIL LOSS	CONTINUOUS WHEAT GRAIN YIELD	STRAW PRODUCED	STRAW NEEDED 1/	SURPLUS STRAW 2/
	1000 ha	t/ha/yr	t/ha/yr	q/ha	q/ha	q/ha	q/ha
Anselmo Fine Sandy Loam	0.8	193.0	96.4	16.8	28.5	16.3	-2.1
Armo Loam 1-3%S	2.9	193.0	96.3	16.1	27.4	16.3	-2.6
Armo Loam 3-7%S	3.4	193.0	96.3	14.1	24.0	16.3	-4.3
Armo Loam 3-7%SE	1.0	193.0	96.3	12.1	20.6	16.3	-6.0
Campus-Carlson Complex	4.9	150.0	75.1	12.1	20.6	14.5	-4.2
Corinth Silty Clay Loam 1-3%S	0.2	193.0	96.3	13.4	22.8	16.3	-4.9
Corinth Silty Clay Loam 3-7%S	1.9	193.0	96.3	11.4	19.4	16.3	-6.6
Crete Silty Clay Loam 0-1%S	3.2	193.0	96.3	21.5	36.5	16.3	2.0
Crete Silty Clay Loam 0-1%TSV	0.2	193.0	96.3	18.2	30.8	16.3	-0.9
Detroit Silt Loam	1.5	142.0	70.8	20.2	34.3	14.2	2.0
Eltree Silt Loam 0-1%S	0.8	142.0	70.8	22.9	38.8	14.2	5.2
Eltree Silt Loam 1-3%S	2.6	142.0	70.8	21.5	36.6	14.2	4.1
Eltree Silt Loam 3-7%S	2.1	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 0-1%S	17.5	142.0	70.8	21.5	36.6	14.2	4.1
Harney Silt Loam 1-3%S	14.6	142.0	70.8	20.2	34.3	14.2	3.0
Harney Silt Loam 3-7%S	4.1	142.0	70.8	17.5	29.7	14.2	0.7
Harney Silty Clay Loam 2-5%SE	8.1	157.0	78.4	16.1	27.4	14.7	-1.0
Harney Armo Complex 3-7%SE	8.9	128.0	63.9	14.8	25.1	13.4	-0.9
Harn.-Carls. Silt Loam 0-1%S	2.0	142.0	70.8	18.2	30.8	14.2	1.2
Harn.-Carls. Silt Loam 1-3%S	18.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 0-1%S	0.7	142.0	70.8	17.5	29.7	14.2	0.7
Harn.-Wak. Silt Loam 1-3%S	6.5	142.0	70.8	16.8	28.6	14.2	0.1
Holdrege Silt Loam 0-1%S	0.5	142.0	70.8	22.9	38.8	14.2	5.2
Holdrege Silt Loam 1-3%S	1.2	142.0	70.8	21.5	36.6	14.2	4.1
Hord Silt Loam	2.8	142.0	70.8	22.9	38.8	14.2	5.2
McCook Fine Sandy Loam	0.4	143.0	96.3	20.2	34.3	16.3	0.9
McCook Silt Loam	2.3	142.0	70.8	16.8	28.6	14.2	0.1
Mento Silt Loam 0-1%S	0.3	142.0	70.8	15.5	26.3	14.2	-1.1
Mento Silt Loam 1-3%S	8.5	142.0	70.8	13.5	22.8	14.2	-2.8
Mento Silty Clay Loam	1.1	157.0	78.4	12.1	20.6	14.7	-4.4
Mento Soils	6.4	145.0	72.2	10.8	18.3	14.2	-5.1
Munjor Sandy Loam	1.4	193.0	96.3	16.1	27.4	16.3	-2.6
New Cambria Silty Clay	0.7	193.0	96.3	17.5	29.7	16.3	-1.5
Boxbury Silt Loam	6.8	142.0	70.8	22.9	38.8	14.2	5.2
Boxbury Silt Loam Fre. Flded	11.2	142.0	70.8	16.8	28.6	14.2	0.1
Wakeen Silt Loam 1-3%S	2.4	142.0	70.8	14.8	25.1	14.2	-1.7
Wakeen Silt Loam 1-3%SE	0.2	142.0	70.8	10.1	17.1	14.2	-5.7
Wakeen Silt Loam 3-7%S	4.2	142.0	70.8	11.4	19.4	14.2	-4.5
Wann Loam	1.4	142.0	70.8	16.8	28.6	14.2	0.1

1/ Assumes straw is left flat.
2/ Assumes 50% of straw is buried by tillage.

To further assess the erosion in the county, one must know the distribution of the various crops grown on each soil. For example, what portions of the 800-ha Anselmo fine sandy loam are planted to wheat, sorghum, or maize and what portions are in fallow? In addition, what are the dominant tillage and residue management practices on that soil?

But let us consider an area even larger than a county. In the USA a convenient size for assessing wind erosion is the land resource area (LRA), composed of land resource units, each usually several thousand hectares in extent and characterized by a particular pattern of soil (including slope and erosion), climate, water resources, land use, and type of farming. (Major land resource areas consist of geographically associated land resource units; major land resource regions consist of geographically associated major land resource areas, Austin, 1972.)

For example, let us consider the counties of LRA 72 in Kansas. This area contains 24 counties with a total land area of 5.5×10^6 ha (13.6×10^6 acres) and 3.9×10^6 ha (9.7×10^6 acres) of cropland. The major crops (with area and yield of each) are shown in Table 2. The amount of residue produced per unit land area was estimated from grain yield data, assuming that the residue/grain ratio is 1.0 for maize and sorghum and 1.7 for wheat. Approximately 10% of the wheat planted was not harvested.

Table 2 LAND RESOURCE AREA 72 - 24 KANSAS COUNTIES - 1975-76 YIELD DATA

CROP	AREA	YIELD	RESIDUE 2/	POTENTIAL SOIL LOSS 1/ 1	2	3
	1 000 ha	q/ha		t/ha/yr		
Irrigated maize	652	67	67	75	22	16
Sorghum	402	35	35	75	43	31
Hay	137	67	0	0	0	0
Continuous wheat	70	13	23	52	34	25
Fallow wheat	1 273	19	33	40	22	16
Fallow (no crop)	1 273	0	0	75	29	18
Wheat (PNH) 3/	123	0	0	75	45	34
	3 931					

TOTAL LAND INVENTORY AREA: 5 502 700 ha

1/ See text for conditions.
2/ Estimated amount of residue after harvest.
3/ PNH = Planted but not harvested.

Average annual soil loss was estimated by the wind erosion equation (Woodruff and Siddoway, 1965) for three combinations of conditions: 1) Wide field, 1/ bare of residue and with rough surface. 2) Wide field with semi-ridged surface - 1/4 of maize and sorghum residue left standing (30 cm tall), 1/4 flattened on the surface, and the other 1/2 removed; 1/4 of continuous wheat residue on surface plus protective value of growing wheat (seedling and stooling) equivalent to 1/10 residue produced; fallow with 1/5 of the residue produced remaining on surface; wheat (planted, not harvested) with residue equivalent to 1/4 of residue produced in continuous wheat production. 3) Same conditions as 2 except that the field is 200 m (660 ft) wide. The means for the area were 86 and 78, respectively for erodibility I and climatic factor C.

The average annual soil loss for the cropland in the 24-county area, according to the relationship of the wind erosion equation, was 60, 27, and 18 metric tons per hectare for the three levels of assumed management. Most of the non-cropland is rangeland. Assuming that the non-cropland is non-erosive, the average soil loss for the total inventory land area became 43, 20, and 13 t/ha/yr, respectively, for the three levels of management. That corresponds to 588, 274, and 184 million metric tons of soil.

4. ASSESSING WIND EROSION HAZARD FROM BASIC SOIL ERODIBILITY AND CLIMATIC POTENTIAL TO CAUSE WIND EROSION

Two (erodibility and climatic factor) of the five independent variables of the wind erosion equation are basic to the soil and climate of the region and are less alterable by management than are the others. Used together, soil erodibility index and climatic factor show promise for use in assessing wind erosion hazard.

Erodibility Index

Soil erodibility (ease of detachment and transport by wind) is a primary variable affecting wind erosion. From wind tunnel tests, Chepil (1950) determined relative erodibilities of soils (reasonably free from organic residues) as a function of apparent specific gravity and proportions of dry soil aggregates in various sizes. Since then, the non-erodible soil fraction greater than 0.84 mm, as determined by dry sieving, has been used to indicate erodibility of soil by wind. In an early version of the wind erosion equation (Chepil and Woodruff, 1954), erodibility was one of three major factors developed from results obtained principally with a portable wind tunnel (Zingg, 1951a, 1951b; Zingg and Woodruff, 1951).

A dimensionless soil erodibility index, I, (Chepil, 1958; Chepil and Woodruff, 1959) was based on the non-erodible fraction (percentage of clods exceeding 0.84 mm diameter). The quantity of soil eroded in a tunnel is governed by the tunnel's length and other characteristics; therefore, erodibility was expressed on a dimensionless basis so that for a given soil and surface condition, the same relative erodibility value would be obtained regardless of wind tunnel characteristics (Chepil, 1960). The soil erodibility index was expressed as

$$I = X_2/X_1 \qquad (1)$$

where X_1 is quantity eroded from soil containing 60 percent of clods exceeding 0.84 mm, and X_2 is the quantity eroded under the same set of conditions from soil containing any other proportions of clods exceeding 0.84 mm. Soil erodibility index, I, gave a relative measure of erodibility, but actual soil loss by wind was not known.

1/ Wide field means that any further increase in width would not increase erosion hazard. This condition usually occurs for a field between 500 and 1 000 metres.

Therefore, during the severe wind erosion of 1954-56 (1 January through 30 April) 69 fields were studied in western Kansas and eastern Colorado to determine the quantity of soil loss for any field erodibility as determined from various field conditions (Chepil, 1960). The average depth of soil eroded usually was indicated by depth to which wheat crowns and roots were exposed.

Seasonal loss was converted to annual soil loss, and relative field erodibility for each field was determined by procedures previously outlined (Chepil, 1959; Chepil and Woodruff, 1954; Chepil and Woodruff, 1959). The relation between annual soil loss and relative field erodibility was

$$Y = aX^{b} - 1/cd^{X} \tag{2}$$

where Y is annual soil loss (tons per acre); X is dimensionless relative field erodibility; and a, b, c, and d are constants equal to 140, 0.287, 0.01525 and 1.065, respectively. Chepil (1960) recognized that inaccuracies in measuring relatively small annual soil losses from depth of soil removal made conversion of relative field erodibility to annual soil loss by equation 2 highly approximate.

When a field is smooth, bare, wide, unsheltered, and noncrusted, its relative erodibility is equivalent to the soil erodibility index defined by equation (1). When I from equation (1) is substituted for X in equation (2), potential annual soil loss in tons per acre is obtained.

Although percentages of non-erodible fractions vary seasonally with management practices and chemical composition of soil, erodibility is strongly influenced by particle size distribution of the soil. Sands, for example, have insufficient fine material to cement the grains into larger aggregates, and much of the soil mass is single grained and, consequently, very erodible. Further research is needed before we can define erodibility precisely as a function of soil, climate, and management; however, we can reasonably estimate a soil's erodibility based on the textural classification of the soil. Therefore, knowledge of surface soil texture distribution in a region provides a basis for estimating susceptibility of the soil to erosive winds.

Climatic Factor

The climatic factor is an index of the average rate at which soil is moved by wind as influenced by moisture content in surface soil particles and average windspeed. Chepil et al. (1962) proposed a climatic factor to determine average annual soil loss for climatic conditions other than those pertaining when the relationship between wind tunnel and field erodibility was obtained.

The soil moisture term of the climatic factor of the wind erosion equation was developed on the basis that erodibility of a soil varies inversely with the equivalent moisture in surface soil particles (Chepil, 1956). Effective moisture of the surface soil particles was assumed to vary as indicated by the Thornthwaite (1931) P-E index developed to evaluate precipitation effectiveness. The P-E index is the sum of 12 monthly precipitations divided by evaporation ratios.

The soil-moisture term of the climatic factor needs refining. The current procedures assume that effective moisture of the surface soil particles varies with the P-E index, but surface moisture content is transient (Idso et al., 1974; Jackson, 1973; Jackson et al., 1973). Drying rate and dryness of particles are functions of hydraulic soil properties and climatic variables not fully reflected in the P-E index. These relationships need examining and then relating to the wind erosion process.

The windspeed term of the climatic factor is based on the assumption that rate of soil movement is proportional to windspeed cubed. Several researchers (Bagnold, 1943; Chepil, 1945; Zingg, 1953) have reported that when windspeeds exceed those required barely to move the soil, the soil-movement rate is directly proportional to friction velocity cubed. Over a specified surface, windspeed and friction velocity are proportional.

The long-term average windspeed and soil moisture index at Garden City, Kansas, was the reference for the climatic factor. It was expressed as

$$C = 100\ u^3/2.9\ (P-E)^2$$

where u is the corrected mean annual windspeed for a standard height of 30 feet, P-E is an index of equivalent moisture in surface soil particles, and 2.9 is the approximate average value of $u^3/(P-E)^2$ for Garden City, Kansas.

Monthly windspeeds are used in lieu of annual windspeeds to determine monthly C values for calculating erosion when plant damage of certain periods of the year is the major interest (Woodruff and Armbrust, 1968). Climatic-factor maps have been prepared for the major wind erosion areas of the USA (Skidmore and Woodruff, 1968). Figures 1 and 2 show that in 1975-76 in the Great Plains the climatic factor and wind erosion damage to cropland were similar.

The product of an appropriate climatic factor and soil erodibility index indicate intensity of wind erosion hazard (WEH) for wide, smooth fields bare of vegetation. Suppose the land in a region is divided into n erodibility groups, each with area A_i and associated erodibility index I_i and climatic factor C_i. Then the mean wind erosion hazard for that region would be

$$WEH = \sum_{i=1}^{n} A_i I_i C_i \ / \ \sum_{i=1}^{n} A_i .$$

As other data such as amount and kind of vegetative cover become available, they can be included in the calculation. Also, because I and C vary seasonally and yearly, it may be desirable to calculate probabilities.

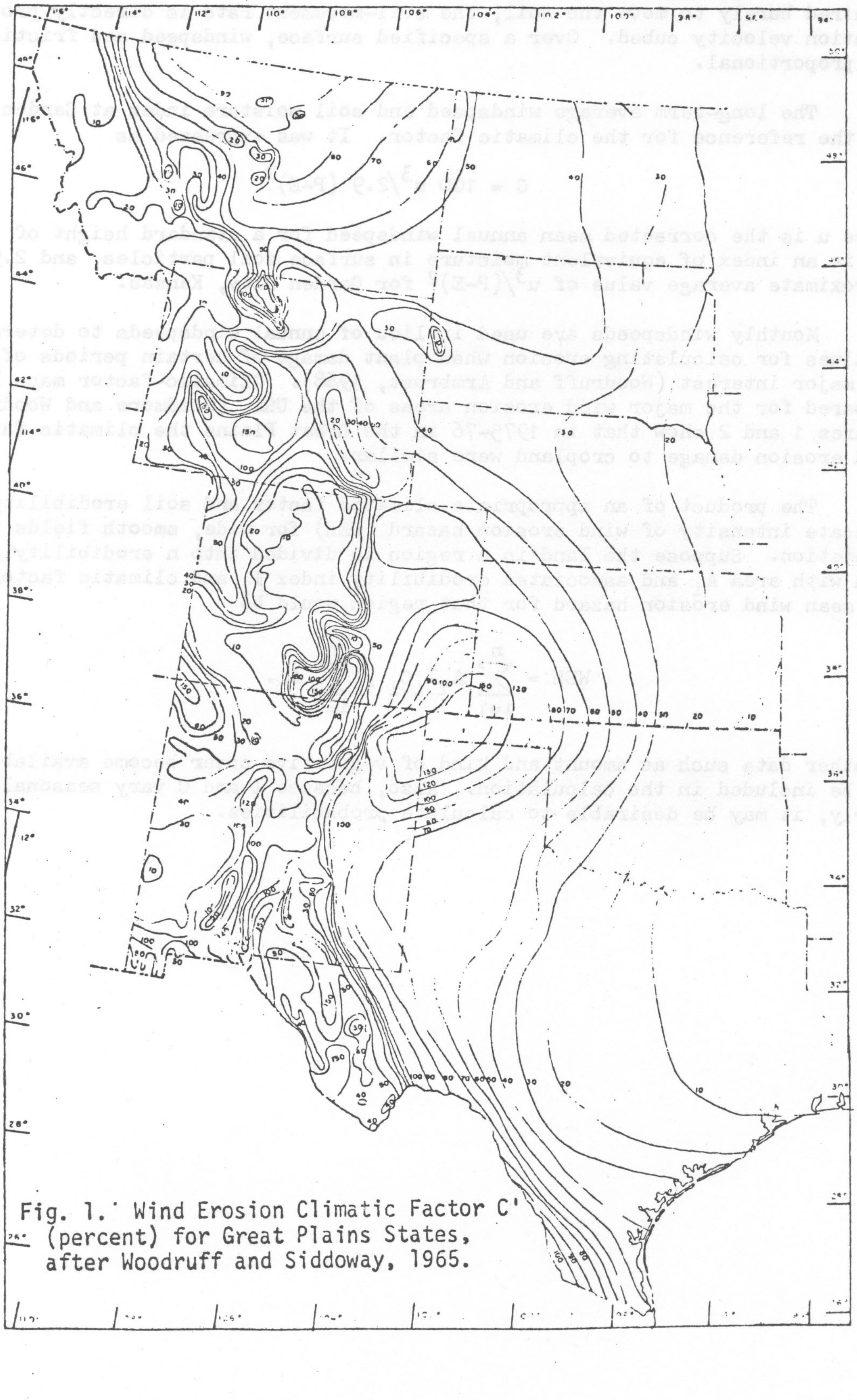


Fig. 1. Wind Erosion Climatic Factor C' (percent) for Great Plains States, after Woodruff and Siddoway, 1965.

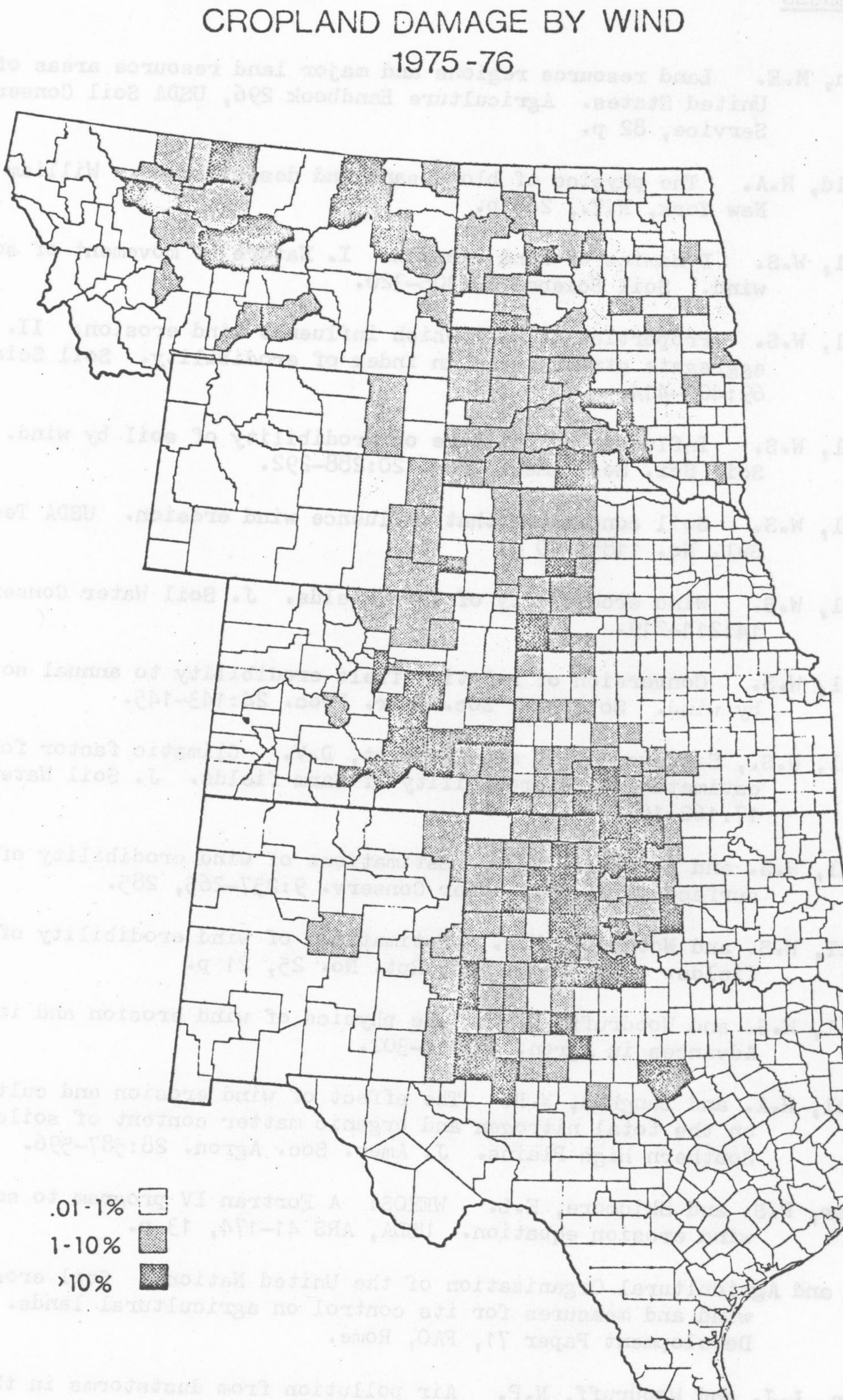


Fig. 2. Percentage of cropland damaged by wind erosion, summarized from data reported by U.S. Dept. of Agriculture, Soil Conservation Service.

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