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Equivalent Wind-Erosion Protection from Selected Crop Residues

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ABSTRACT

A wind erosion equation, which estimates annual potential erosion, requires that all vegetative cover (dry weight per area) be expressed as a small grain equivalent. Wind-tunnel tests were used to determine that equivalent for seven crops: cotton, forage sorghum, rape, silage corn, soybeans, sunflowers, and winter wheat—five at two orientations (standing and flat-random). Among the crops and orientations tested, standing winter wheat residue was the most effective for wind erosion protection and flat-random sunflowers the least effective. Multiple regression equations were determined, or where available, used, for extending the results to any other crop characterized by amount and stalk diameter, height, and specific weight. The small grain equivalents data along with other factors in the wind erosion equation, may be used to predict potential wind erosion at specific crop sites or to determine residue amounts needed to hold potential wind erosion to tolerable limits.

INTRODUCTION

Managing living and dead vegetative cover is the most effective and practical method for controlling wind erosion (Woodruff et al., 1977). A vegetative material's effectiveness depends on the quantity, kind, and orientation in relation to the soil surface (including areal distribution) (Chepil, 1944; Siddoway et al., 1965; Lyles and Allison, 1976). In current procedures for evaluating or designing management systems for wind erosion control, the following wind erosion equation is used (Woodruff and Siddoway, 1965):

$$E = f(I, K, C, L, V), \qquad [1]$$

where E is the potential annual soil-loss rate; I, the soil erodibility; K, the soil ridge roughness factor; C, the climatic factor; L, the unsheltered median travel distance of the wind across a field, and V, the equivalent vegetative cover. To use the equation, all vegetative cover (dry weight per unit area) must be expressed in terms of its equivalent to a small grain standard. The standard (reference) has been defined as 25.4 cm (10 in.) of dry small grain stalks lying flat on the soil surface in rows perpendicular to wind direction with 25.4-cm (10-in.) row spacing, with stalks oriented parallel to the wind direction.

Equivalents data are available for several range grasses (Lyles and Allison, 1980) and agronomic crops; we initiated this study to determine the small grain equivalent of other selected crops as requested by the Soil Conservation Service.

EXPERIMENTAL PROCEDURE

The selected crop residues were all obtained after harvest—winter wheat, soybean, forage sorghum, and silage corn near Manhattan, KS; rape near Dighton, KS; and cotton and sunflowers near Big Spring, TX. In the laboratory the residues were washed and air-dried before wind-tunnel testing. A minimum of 100 stalks was used to determine average stalk diameter and specific weight (Table 1).

The laboratory wind-tunnel, 1.52 m wide, 1.93 m high, and 16.46 m long, was a recirculating push-type tunnel with airflow generated by a 10-blade, variable-pitch axivane fan. The appropriate kind, amount, and height of standing residue (described specifically in Table 2) was placed in standard test trays 148 cm long, 16.5 cm wind, and 4 cm deep (inside dimension). The trays were then filled with erodible sand 0.297 to 0.42 mm in diameter. For the flat residue orientation the trays were filled with the sand and smoothed, and then the residues were randomly placed on the surface. Random here means that the stalks were overlapping with no discernible row direction or spacing and nonparallel to wind direction—all different from the reference small grain orientation. Two test trays were located approximately 14.5 m downwind and 7 cm apart (side by side) during each exposure to wind. The entire wind-tunnel floor area downwind and 4.9 m upwind from the test area was covered with the same number of stalks per unit area as the test trays contained. The trays were exposed for 5 min at 13.36 m/s freestream windspeed in the tunnel. The sand loss was determined from the differences in tray plus sand weight before and after exposure to wind. Generally, three replications (six test trays) of each residue amount and five to seven different amounts of residue were tested to establish the relationship between the sand loss rate and the dry weight per unit area of each crop.

Winter wheat stubble, displayed in the reference manner, was tested under the same conditions as were the other crops to provide the basis for comparison required for determining small grain equivalents.

RESULTS

Fig. 1 shows typical curves of sand loss rate as related to the amounts of dry vegetation for selected crops and

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TABLE 1. AVERAGE STALK DIAMETER AND SPECIFIC WEIGHT OF VARIOUS CROPS TESTED

Crop	Stalk diameter	Specific weight	Variety
	cm	g/cm^3	
Winter wheat (*Triticum aestivum* L.)	0.29*	0.16	Scout
Rape (*Brassica rapa* L.)	0.59*	0.26	Tower
Soybeans (*Glycine max* (L.) Merr.)	0.66*	0.39	Clark-63
Cotton (*Gossypium hirsutum* L.)	0.78*	0.56	Western stormproof
Forage sorghum (*Sorghum bicolor* (L.) Moench.)	1.38†	0.38	Ellis
Silage corn (*Zea mays* L.)	2.51†	0.20	KDS-synthetic
Sunflowers (*Helianthus annus* L.)	1.57‡	0.26	Sun-Hi 66

*Lower 25 cm.
†Lower 16 cm.
‡Lower 43 cm.

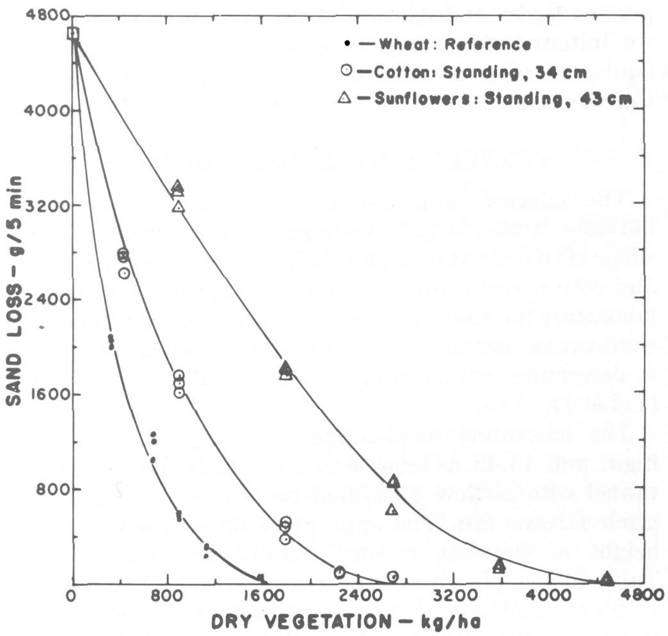

FIG. 1 Wind-tunnel sand loss as related to amounts of standing vegetation for cotton and sunflowers. Winter wheat is in the reference orientation.

winter wheat. These and similar data for the other crops were converted to an equivalent quantity of flat small grain residue (Figs. 2 to 4). A power equation of the form

$$(SG)_e = aR_w^b \quad [2]$$

correlated the data well, as evidenced by high simple-correlation coefficients (r). In the equation, $(SG)_e$ is the small grain equivalent and R_w is the quantity of residue to be converted, both in kilograms per hectare; and a and b are constants. Specific values for the constants for each crop, along with the corresponding r^2, are given in Table 2.

A simple linear equation of the form

$$(SG)_e = a + bR_w \quad [3]$$

also correlated the data well, but in 10 of 12 cases, the r^2 for equation [2] was slightly larger than equation [3]. For $(SG)_e \leqslant 560$ kg/ha, the power equation fitted the experimental data better than did the linear equation in 44 of 48 observations; however, for $560 < (SG)_e \leqslant 1570$ kg/ha, the linear equation gave a better fit in 38 of 60 observations.

Among the crops and orientations tested, standing winter wheat was the most effective for wind erosion protection and flat-random sunflowers the least effective (Figs. 2 and 3).

DISCUSSION

All standing residues were in rows perpendicular to wind direction (flow). Residues in rows parallel to wind direction would be less effective and thus have a lower small grain equivalent than those perpendicular, but no tests of residues in rows parallel to the wind were conducted in this study.

Previous data on small grain equivalents of various

TABLE 2. CROP RESIDUE GEOMETRY TESTED AND COEFFICIENTS FOR PREDICTION EQUATION: $(SG)_e = aR_w^b$ (EQUATION [2])

Crop residue	Surface orientation	Height	Length	Row spacing	Row orientation to flow	Prediction equation coefficients a	b	r^2
		cm	cm	cm				
Winter wheat	Standing	25.4	—	25.4	Normal	4.306	0.970	0.997
Rape	Standing	25.4	—	25.4	Normal	0.103	1.400	0.990
Cotton	Standing	34.3	—	76.2	Normal	0.188	1.145	0.998
Sunflowers	Standing	43.2	—	76.2	Normal	0.021	1.342	0.994
Winter wheat	Flat-random	—	25.4	—	—	7.279	0.782	0.993
Soybeans	Flat-random	—	25.4	—	—	0.167	1.173	0.993
Rape	Flat-random	—	25.4	—	—	0.064	1.294	0.997
Cotton	Flat-random	—	25.4	—	—	0.077	1.168	0.998
Sunflowers	Flat-random	—	43.2	—	—	0.011	1.368	0.993
Forage sorghum	Standing	15.9	—	76.2	Normal	0.353	1.124	0.995
Silage corn	Standing	15.9	—	76.2	Normal	0.229	1.135	0.998
Soybeans	1/10 standing	6.4	—	76.2	Normal	0.016	1.553	0.991
	9/10 flat-random	—	25.4	—	—			

TABLE 3. PREVIOUS EQUIVALENTS DATA (CHART 3, USDA, 1973) COMPARED WITH DATA IN OUR STUDY FOR WINTER WHEAT, COTTON, AND CORN. VALUES WERE COMPUTED FROM POWER EQUATION $(SG)_e = aR_w{}^b$ (EQUATION [2])

	R_w							
	Standing wheat		Standing cotton		Shredded cotton*		Corn, 20 cm	
$(SG)_e$	This study	Chart 3	This study	Chart 3	This study	Chart 3	This study†	Chart 3
kg/ha								
90	22	28	219	202	423	251	193	122
224	58	82	485	647	926	855	430	375
448	120	183	889	1562	1676	2164	794	880 ‡
897	245	410	1629	3769	3033	5473	1460	2061
1345	372	657	2321	6310	4292	9418	2087	3391
1793	501	918	2984	9094	5490	13842	2689	4829
2242	631	1189	3625	12076	6647	18661	3273	6351

*Assumed shredded cotton in "chart 3" was similar to flat-random cotton in this study.

†In this study, 16 cm.

‡Residue amounts below this line are generally too large to be produced by these crops.

crops in use by the Soil Conservation Service were expressed graphically and called "chart 3" (U.S. Department of Agriculture, 1973). Where possible, chart 3 data were compared with those in this study by using equation [2] for both (Table 3). Except for low amounts, residues were more effective in this study than were residues measured or estimated previously, as shown by data in chart 3. The origin of some data in chart 3 is unknown, but we believe that those for some crops, e.g. cotton, are estimates based on personal judgment of residue height, stalk diameter, row spacing, and other factors relative to small grain.

A question arises concerning how crops that have not been tested in a wind tunnel should be evaluated. A more general equation is needed, one involving measurable parameters that physically describe the crop residues in question. We correlated many "independent" variables and combinations of variables with $(SG)_e$ by using stepwise multiple regression where variables were entered in the order of their greatest contribution to variance. Because of variance accounted for, simplicity, and realism of predicted values, we selected this prediction equation for flat-random residues:

$$(SG)_e = 0.162\ R_w/d + 8.708\ (R_w/d\gamma)^{1/2} - 271;\quad R = 0.96 \qquad [4]$$

where $(SG)_e$ is flat small grain equivalent (kg/ha), R_w is residue amount to be converted (kg/ha), d is average stalk diameter (cm), and γ is average specific weight of stalk (g/cm^3). Five crops (winter wheat, rape, soybeans, cotton, and sunflowers) were used in developing equation [4]. Stalk diameter ranged from 0.29 to 1.57 cm and specific weight from 0.16 to 0.56 g/cm^3. A comparison between equation [2] and equation [4] shows good agreement for flat-random winter wheat and flat-random sunflowers (Table 4).

TABLE 4. EQUATION [2] AND EQUATION [4] COMPARED, FOR PREDICTING THE SMALL GRAIN EQUIVALENT OF FLAT-RANDOM WINTER WHEAT AND FLAT-RANDOM SUNFLOWERS

Flat-random winter wheat	$(SG)_e$ Eqn [2]	$(SG)_e$ Eqn [4]	Flat-random sunflowers	$(SG)_e$ Eqn [2]	$(SG)_e$ Eqn [4]
kg/ha					
112	299	219	560	63	109
224	514	459	1121	163	301
560	1052	998	2242	422	606
841	1445	1370	3363	734	866
1121	1810	1707	4483	1088	1104

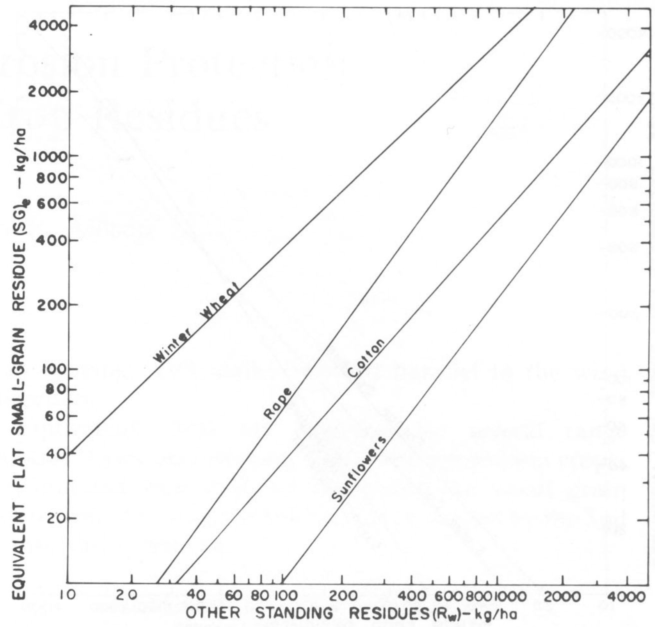

FIG. 2 Converting standing winter wheat, rape, cotton, and sunflower residues to quantity of equivalent flat, small grain residue. Residue data and prediction equation coefficients are given in Table 2.

Because in our study there was no height variation within a specific crop, no valid general equation for predicting the small grain equivalent of standing residues could be developed from the test data. However, by using a critical friction velocity ratio (CFVR) equation (Lyles and Allison, 1976), the protective ability (on a dry-weight basis) of standing grain sorghum and corn stubble relative to standing wheat stubble was determined for equal values of the CFVR among crops. Because data were available to convert standing wheat stubble to its small grain equivalent (Fig. 2), standing grain sorghum and corn could be converted to their small grain

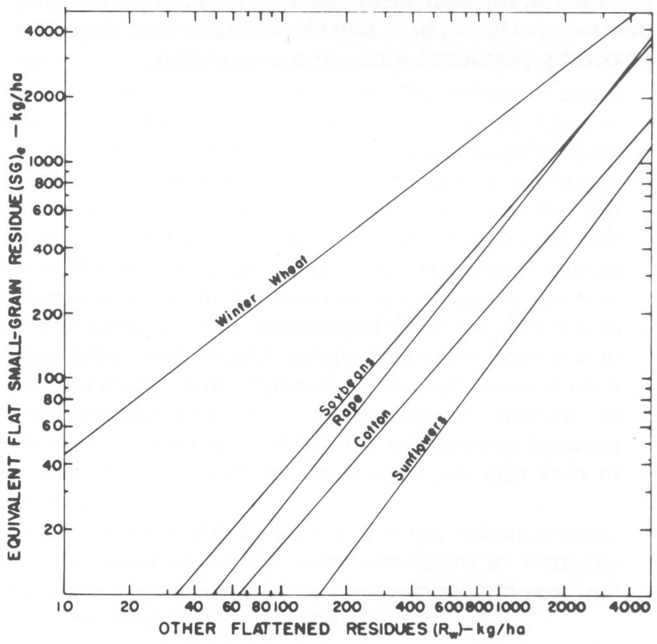

FIG. 3 Converting flat-random winter wheat, soybeans, rape, cotton, and sunflower residues to quantity of equivalent flat, small grain residue. Residue data and prediction equation coefficients are given in Table 2.

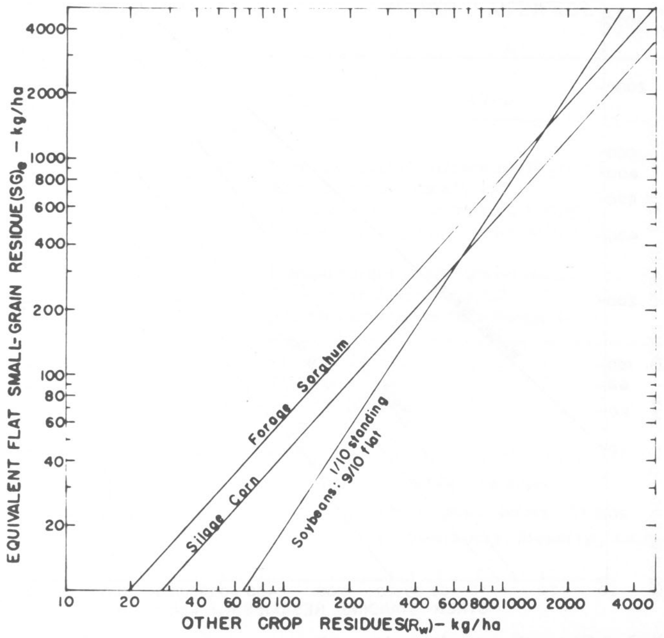

FIG. 4 Converting forage sorghum, silage corn, and soybean residues to quantity of equivalent flat, small grain residue. Residue data and prediction equation coefficients are given in Table 2.

equivalents (Fig. 5). Also in Fig. 5, equation [4] was applied to untested crop residues of flat-random grain sorghum (d = 1.77 cm; γ = 0.14 g/cm^3) and flat-random corn (d = 2.51 cm; γ = 0.17 g/cm^3). Equivalents values for flat grain sorghum agree with those given in "chart 3" (USDA-SCS, 1973), but we found flat corn stubble to be inferior to grain sorghum (equation [4]). That agrees with data of Lyles and Allison (1976) but disagrees with "chart 3's" assumption that they are equal.

Once solutions to equation [4] or the CFVR equation are obtained for a given crop at several selected residue weights (R_w), graphs similar to Figs. 2 to 5 may be prepared and used for future conversions of that crop to its small grain equivalent. Of course, data on the four parameters (R_w, d, h, γ) must be available and they must physically characterize the crop in question.

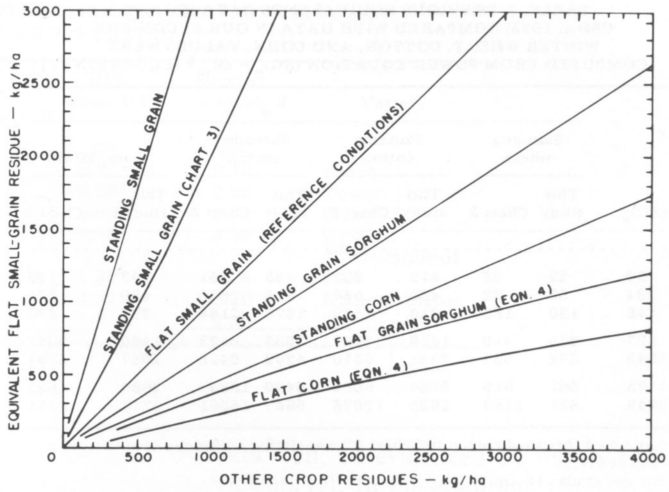

FIG. 5 Converting corn and grain sorghum residues to quantity of equivalent flat, small grain residue.

The small grain equivalents data (along with other factors in the wind erosion equation) will be useful in predicting the erosion potential of specific crop sites or in determining amounts of residues needed to hold potential erosion to tolerable limits.

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