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Abstract. *Surface microrelief is frequently characterized using random roughness factors (RRF) defined by Allmaras et al. (1966). Random roughness factors are usually measured using a pin roughness meter or laser. Saleh (1993) recently proposed the chain method as a relatively simple, fast, and inexpensive technique for characterizing surface microrelief. The chain method is based on the principle that as a chain of given length is placed across a surface, the horizontal distance covered by the chain will decrease as surface roughness increases. Reductions in chain length caused by surface roughness are described as Saleh roughness factors (SRF).*

In this study, RRF and SRF were identified for a wide range of surface roughness conditions. The standard deviations in SRF obtained on a 1 m² area were reported. Regression equations were developed for estimating RRF and SRF. The equations, which include rainfall as a dependent variable, can be used for RRF varying from 2.59 to 37.23 mm (0.10 to 1.47 in.) and SRF ranging from 2.65 to 34.56. The chain method provides an easily obtained direct estimate of surface roughness. **Keywords.** *Microrelief, Random roughness, Soil roughness, Surface roughness, Tillage.*

Kuipers (1957) was one of the first to develop a procedure for quantifying small surface depressions or microrelief. He used surface elevation readings to characterize roughness elements which occurred randomly, such as clods, and oriented roughness elements which were created by tillage tools or tire tracks. Significant variations in microrelief between tillage systems were found by Burwell et al. (1963). Excessively wet or dry conditions at the time of tillage resulted in greater roughness than when tillage was performed at an ideal soil water content (Burwell et al., 1966).

Allmaras et al. (1966) employed height measurements to calculate parameters they defined as random roughness factors (RRF). The effects of slope and oriented tillage tool marks were mathematically removed to reduce the variation among elevation measurements. The upper and lower 10% of the readings were also eliminated to minimize the effect of erratic height measurements on the final result.

Random roughness factors have been widely used as a measure of surface microrelief. An extensive database is available in the literature which provides RRF for various tillage operations, soil types, and soil water conditions (Allmaras et al., 1967; Burwell and Larson, 1969; Steichen, 1984). The effects of rainfall on RRF have also been evaluated (Onstad et al., 1984).

Zobeck and Onstad (1987) performed a comprehensive review of the literature concerning RRF. They provided representative RRF for single- and multiple-pass tillage operations, and derived equations for estimating reductions in random roughness due to rainfall. For most agricultural soils, tillage and rainfall were found to be the primary factors affecting surface microrelief.

Several other parameters have been used to characterize surface microrelief (Currence and Lovely, 1970; Podmore and Huggins, 1980; Linden and VanDoren, 1986; Romkens and Wang, 1986; Potter and Zobeck, 1990; Potter et al., 1990). Several of these parameters have considerable potential for use in describing soil roughness. However, lack of a broad database has limited the usefulness of other surface roughness parameters, and they have not received wide acceptance.

Random roughness factors developed by Allmaras et al. (1966) are being used extensively. Point elevation readings obtained using a pin roughness meter or laser are required to calculate RRF. Collection and analysis of roughness meter data can be tedious and time consuming.

Saleh (1993) proposed the chain method as a relatively simple, fast, and inexpensive technique for determining surface roughness. The chain method is based on the principle that as a chain of given length is placed across a surface, the horizontal distance covered by the chain will decrease as surface roughness increases. Reductions in chain length caused by soil surface roughness are described in the present article as Saleh roughness factors (SRF).

Experimental Procedures

Experimental Design

Field tests were conducted at the University of Nebraska Rogers Memorial Farm located approximately 18 km

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(11 mile) east of Lincoln, Nebraska. The Sharpsburg silty clay loam at the site (fine, montmorillonitic, mesic Typic Argiudolls) formed on loess under prairie vegetation. Sand, silt, and clay content of the soil were approximately 5, 55, and 40%, respectively, and average slope at the location was 6.4%.

The experimental design consisted of two randomized complete blocks, with the first block located immediately upslope from the second. Each experimental block contained six tillage operations performed on the contour at random locations within the block. The tillage operations included an anhydrous ammonia applicator, chisel plow, disk, field cultivator, moldboard plow, and planter. These implements were chosen to provide a wide range of random roughness conditions.

Existing wheat residue was first removed from the study area by burning and hand raking. Selected tillage operations were then performed along the contour. Plots 1 m^2 were established within each tillage treatment using galvanized sheet metal borders for the top and both sides of the plots. Further details concerning experimental procedures are given by Gilley and Finkner (1991).

Rainfall Simulation

Rainfall was applied using a variable rate simulator built using a design similar to that of Meyer and Harmon (1979). An intensity of 25 mm/h (1 in./h) was used to provide a rainfall rate below the saturated hydraulic conductivity of the soil. Within each implement treatment, individual plots were randomly selected to receive one of five predetermined cumulative rainfall amounts of 0, 35, 75, 150, or 300 mm (0, 1.4, 3.0, 5.9, or 11.8 in.). Rainfall was applied continuously except on the 300 mm (11.8 in.) treatment where the application of rainfall occurred over two consecutive days. Rainfall amounts were measured using two direct reading rain gauges located on opposite sides of the plot. Two plots were used for each tillage condition and rainfall amount for a total of 60 plots.

Random Roughness

Differences in soil surface height were recorded using a mechanical profile meter similar to the device described by Allmaras et al. (1967). The profile meter could be easily rolled above the entire plot surface on a rectangular support frame which could be leveled in the horizontal plane. The rectangular frame was supported by four 250 mm (10 in.) steel stakes which were securely anchored into the soil to provide a horizontal reference. The upper left corner of each plot border as viewed from the bottom of the plots was used as a vertical bench mark, creating a three-dimensional referencing system.

The profile meter consisted of a single row of equal length, 3.2 mm (0.13 in.) diameter steel pins positioned at a spacing of 64 mm (0.25 in.). When lowered onto the soil surface, the top of the pins formed a nearly continuous line which was traced onto a strip of paper located behind the pins. The profile meter and frame were oriented so that surface elevations were measured parallel to the tillage direction. Transects were spaced every 50 mm (2 in.) along the slope and transect traces were later digitized at 25 mm (1 in.) spacings. A total of 629 surface elevations were used to determine RRF for each 1 m^2 plot.

Saleh Roughness Factors

Saleh roughness factors were developed using the principal that the surface distance between two points will become larger as soil roughness increases. Therefore, a chain of given length, L1, will traverse a shorter horizontal distance, L2, when it follows a rough surface compared to a smooth surface. The following equation was used to obtain SRF (Saleh, 1993):

$$SRF = 100\,(1 - L2/L1) \qquad (1)$$

Using the above equation, microrelief caused by aggregates, C_{rr}, can be determined using measurements obtained in a direction parallel to ridges. Roughness in a direction perpendicular to the ridges, C_{pr}, is caused by both ridges and aggregates. The following equation can be used to determine oriented roughness, C_{or}, caused just by ridges:

$$C_{or} = C_{pr} - C_{rr} \qquad (2)$$

In this study, only C_{rr} was identified.

Transects obtained in the field by the profile meter were used to calculate SRF. The transects were located parallel to the tillage direction and thus it was not necessary to make adjustments for oriented roughness. An electronic digitizer was employed to obtain continuous length measurements of the transects (L1). The corresponding horizontal lengths of the transects (L2) were also identified. SRF were then calculated for each transect using equation 1. For each 1 m^2 plot, values from 19 transects were averaged to obtain a single SRF.

Results and Discussion

Random Roughness Factors

Random roughness factors for each tillage condition and rainfall amount are presented in tables 1 through 6. To provide an indication of the amount of variation which might occur between plots, RRF obtained for individual replications are presented. (For a given tillage treatment and rainfall amount, the largest value for the two replications was listed first to provide consistency in the presentation. This value could have been obtained from either of the two experimental plots.)

In general, it can be seen that RRF decreased as cumulative rainfall amounts became larger. However, for

Table 1. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been disturbed with an anhydrous ammonia applicator

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	8.20	12.42 (9.20)
	6.87	14.22 (7.93)
35	8.68	7.11 (7.63)
	6.50	7.58 (3.10)
75	5.25	4.97 (3.68)
	4.80	2.71 (2.54)
150	7.99	3.49 (3.02)
	3.50	4.05 (2.17)
300	2.92	2.89 (1.63)
	2.59	2.65 (1.91)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

Table 2. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been tilled with a chisel plow

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	25.73	34 56 (3.47)
	21.47	30.21 (3.41)
35	15.77	14.47 (4.81)
	12.58	15.72 (5.54)
75	13.37	9.62 (2.62)
	11.42	9.80 (2.42)
150	11.29	13.45 (4.46)
	10.35	8.87 (3.98)
300	9.43	6.99 (3.79)
	8.10	7.14 (4.04)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

some of the experimental treatments, the largest RRF were found on plots that had received rainfall. Substantial variations in surface microrelief existed on some of the treatments following tillage. Even though surface microrelief had been reduced as a result of rainfall, RRF were still greater because of the relatively large initial surface roughness.

Random roughness factors obtained in the present study for the no-rainfall condition and those reported by Zobeck and Onstad (1987) in a review of available literature are presented in table 7. In this investigation, RRF ranged from 6 mm (0.2 in.) for the planter to 34 mm (1.3 in.) for the moldboard plow treatment. Random roughness factor obtained in the present study were similar to values reported by Zobeck and Onstad (1987).

The RRF shown in table 7 represent best estimates for a particular tillage operation. Surface conditions may be affected by differences in soil texture, water content at time of tillage, or tillage depth. Variations in the physical characteristics of the tillage implements may also result in different random roughness values.

Table 4. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been disturbed with a field cultivator

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	10.18	23.86 (4.98)
	9.62	21.26 (5.77)
35	10.64	13.12 (4.27)
	7.50	8.23 (4.05)
75	7.46	7.81 (3~38)
	4.09	5.90 (4.43)
150	6.00	6.73 (4.66)
	4.12	5.80 (3.49)
300	3.65	5.65 (2.34)
	3.25	2.79 (2.15)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

Saleh Roughness Factors

Saleh roughness factors for each of the experimental treatments are also shown in tables 1 through 6. In general, SRF were reduced substantially as cumulative rainfall amounts became larger. The standard deviation of measurements was usually the largest on those plots with the greatest SRF.

Saleh (1993) reported SRF which varied from 0.55 on an almost flat surface to 13.12 for a moldboard plowed surface which had received rainfall. In the present study, SRF for moldboard plowed surfaces with rainfall ranged from 9.47 to 22.65 (table 5).

Saleh roughness factors are similar in magnitude to RRF. For the experimental conditions used in this investigation, SRF varied from 2.65 to 34.56 compared to 2.59 to 37.23 (0.10 to 1.47 in.) for RRF. Changes in surface roughness induced by tillage and rainfall appear to be adequately reflected by SRF.

Estimating Roughness Factors

The information presented in tables 1 through 6 was used to develop figure 1. Figure 1 shows RRF versus SRF for each of the 60 plots. It can be seen from figure 1 that substantial variation occurred among some measurements, particularly those obtained on surfaces with the largest

Table 3. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been tilled with a disc

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	15.46	28.16 (5.83)
	13.22	22.69 (4.51)
35	10.83	14.94 (6.50)
	10.75	16.33 (4.64)
75	12.55	11.89 (3.51)
	8.53	8.78 (3.62)
150	10.21	11.68 (3.60)
	9.36	9.14 (3.76)
300	7.82	5.94 (2.10)
	5.06	4.62 (2.26)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

Table 5. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been tilled with a moldboard plow

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	37.23	30.91 (5.86)
	31.06	33.03 (6.07)
35	32.59	22.65 (4.00)
	19.97	20.06 (5.01)
75	26.08	16.64 (3,.88)
	21.74	16.18 (4.14)
150	26.03	13.64 (4.38)
	18.26	15.64 (3.69)
300	17.57	9.47 (3.48)
	13.75	11.69 (4.00)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

Table 6. Roughness factors following the application of selected amounts of simulated rainfall to initially smooth soil surfaces which had been disturbed with a planter

Simulated Rainfall Amount (mm)*	Random Roughness Factor (mm)*	Saleh Roughness Factor†
0	5.97	12.97 (5.07)
	5.21	11.09 (3.86)
35	4.78	5.32 (2.91)
	4.09	3.90 (1.92)
75	3.46	3.19 (1.,15)
	2.97	3.92 (1.01)
150	4.45	3.59 (0.99)
	3.84	2.67 (1.19)
300	4.77	3.39 (1.98)
	3.27	3.06 (1.79)

* Metric to English unit conversion: 25.4 mm = 1 in.
† Standard deviation is shown in parentheses.

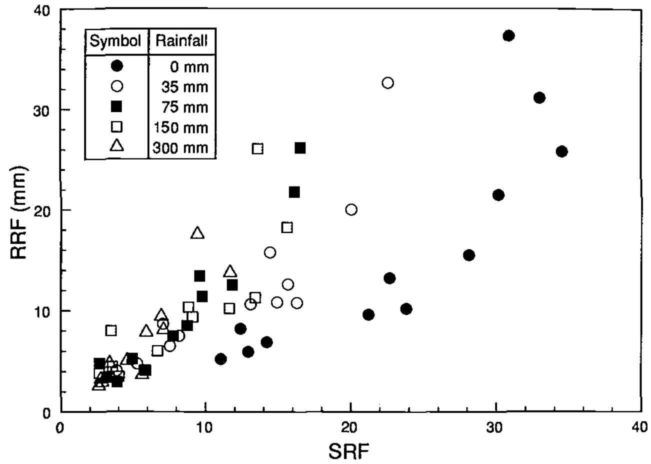

Figure 1–RRF vs. SRF for selected amounts of cumulative rainfall (metric to English unit conversion: 25.4 mm = 1 in.).

microrelief. Rainfall can also be seen to reduce surface roughness.

The following regression equations were obtained for estimating random roughness. Since rainfall has been shown to be an important factor influencing surface roughness, it was included as an independent variable in the equations. The regression equations were developed to be robust and to allow reliable estimates under both rainfall and no-rainfall conditions. For RRF and rainfall given in millimeters (metric to English unit conversion: 25.4 mm = 1 in.):

$$RRF = A\ SRF^{B} \tag{3}$$

where

$$A = 1 - e^{[-4.82 \times 10^{-3}\,(\text{rainfall} + 19.0)]} \tag{4}$$

and

$$B = 1 / \{1 - e^{[-2.95 \times 10^{-3}\,(\text{rainfall} + 321)]}\} \tag{5}$$

A coefficient of determination, r^2, value of 0.82 was obtained for equation 3. Predicted versus actual RRF are shown in figure 2.

Similarly,

$$SRF = C\ RRF^{D} \tag{6}$$

where

$$C = 1 / \{1 - e^{[-5.23 \times 10^{-3}\,(\text{rainfall} + 36.0)]}\} \tag{7}$$

and

$$D = 1 - e^{[-3.40\,(\text{rainfall} + 209)]} \tag{8}$$

A coefficient of determination, r^2, value of 0.92 was obtained for equation 6. Figure 3 shows predicted versus actual SRF.

When SRF are measured in the field, the corresponding RRF may be of interest and equation 3 can be used to provide estimates of RRF. Very little information is presently available on SRF. Equation 6 and currently available measurements of RRF can be employed to predict SRF.

Table 7. Random roughness values for selected tillage operations in the absence of rainfill

Tillage Operation	Random Roughness* (mm)†	Random Roughness (Present Study) (mm)†
Large offset disk	50	
Moldboard plow	32	34
Lister	25	
Chisel plow	23	24
Disk	18	14
Field cultivator	15	10
Row cultivator	15	
Rotary tillage	15	
Harrow	15	
Anhydrous applicator	13	8
Rod weeder	10	
Planter	10	6
No-till	7	
Smooth surface	6	

* T. M. Zobeck and C. A. Onstad (1987).
† Metric to English unit conversion: 25.4 mm = 1 in.

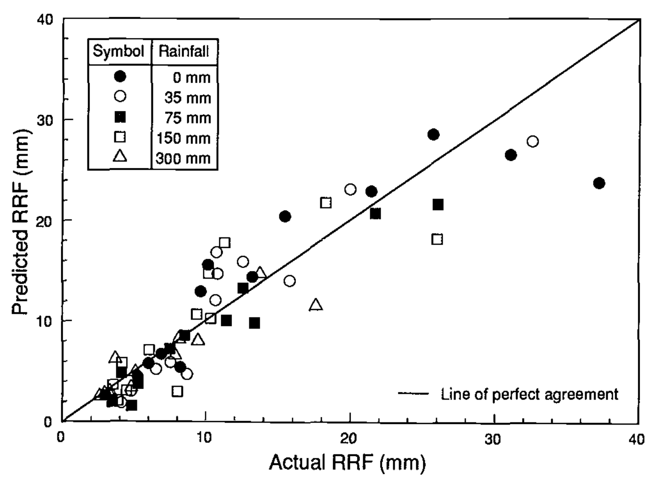

Figure 2–Predicted RRF vs. actual RRF (metric to English unit conversion: 25.4 mm = 1 in.).

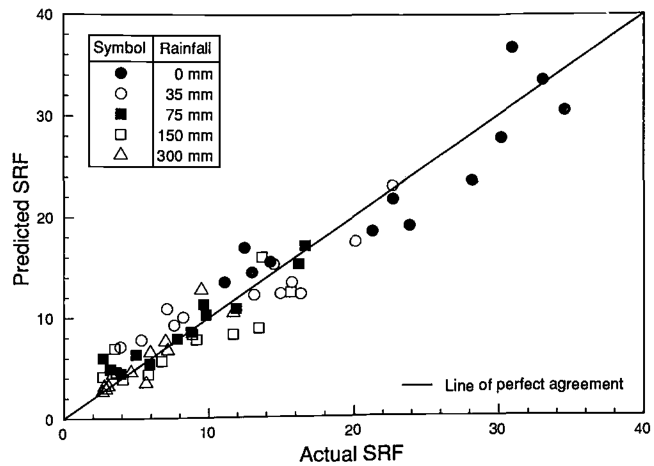

Figure 3–Predicted SRF vs. actual SRF (metric to English unit conversion: 25.4 mm = 1 in.).

Summary and Conclusions

Random roughness factors identified by Allmaras et al. (1966) are widely used to characterize surface microrelief. Measurement of this parameter under field conditions is labor intensive and expensive. Saleh (1993) proposed the chain method as a simpler technique for identifying surface microrelief. The chain method is based on the principle that as a chain of given length is placed across a surface, the horizontal distance covered by the chain will decrease as surface roughness increases. Saleh roughness factors are defined as the reduction in chain length caused by surface microrelief.

A field study was conducted to measure RRF and SRF over a wide range of conditions. Tillage was performed on initially smooth soil surfaces using six tillage operations. For each tillage operation, simulated rainfall was applied to selected plots at five cumulative amounts ranging from 0 to 300 mm (0 to 11.8 in.). Random roughness factors and SRFs were determined on each of 60 experimental plots. Measured RRF were similar to values reported in the literature.

Saleh random roughness factors are similar in magnitude to RRF. Changes in surface roughness induced by tillage and rainfall appear to be adequately reflected by SRF. The chain method provides an easily obtained direct estimate of surface roughness.

The experimental data were used to develop regression equations for estimating RRF and SRF. The regression equations can be used for RRF varying from 2.59 to 37.23 mm (0.10 to 1.47 in.), and for SRF ranging from 2.65 to 34.56. These equations can be employed to estimate RRF from easily made field measurements of SRF. In addition, the equations can be used to predict SRF from the extensive database available in the literature on RRF.

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