APPENDIX N

SOIL SURFACE ROUGHNESS DECAY BY RAINFALL AMOUNT AND EROSIVITY INDEX (EI)

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ABSTRACT

Rainfall amount erosivity index (EI) decay soil aggregates and ridges at different rates. To evaluate the decay of soil aggregates and ridges by natural rainfall amount and EI. Field and rainfall simulator experiments were conducted. One half of a field with fine sandy loam soil, located in West Texas, was tilled with a lister; the other half, with a moldboard plow. Soil surface roughness was measured before and after each rain event. About 500 mm of rainfall (EI = 3113 MJ-mm/ha-hr) melted the soil aggregates completely; whereas, ridges decayed only 58% after 678 mm of rainfall (EI = 4787 MJ-mm/ha-hr). Equations were developed to estimate decay of soil aggregates and ridges from rainfall amount and EI. Because only one soil was used during the field experiment, these equations are not applicable to other soil types. Therefore, a soil roughness decay factor (DF) was developed from rainfall simulator experiments. Aggregates of 16 soils, ranging from fine sandy loam to clay (including the soil used in the field experiment) were irrigated at the same rate and intensity by a rainfall simulator. Soil aggregate roughness was measured before and after simulated rainfall. DF was obtained by computing the ratio of the decay rate of aggregates of 15 soils to that of the field study soil. DF was used to modify the predictive equations for other soils. These modified equations estimating soil aggregate decay were tested by two data sets from the literature.

INTRODUCTION

Soil surface roughness, including ridges (oriented roughness, OR) and aggregates (random roughness, RR) significantly affects wind and water erosion. For instance, soil surface roughness affects soil particle emission and trapping during a wind erosion event (Hagen, 1988). It also reduces the runoff velocity and thus decreases soil detachment and transport (Cogo *et al*., 1983) caused by water erosion.

Soil surface roughness changes considerably with rain, wind, freezing and thawing, and cultivation (Zobeck and Onstad, 1987). Onstad *et al*. (1984) and Römkens and Wang (1985) described the soil aggregate decay as a function of cumulated rainfall.

Potter (1990a) developed an exponential function to predict soil aggregate decay as a function of cumulated rainfall. He related the coefficients in this function to the soil organic carbon and clay content. He concluded that soil aggregate stability increased with the percent clay content up to 31% and then decreased with additional clay.

Other researchers found the need to replace the rainfall amount with a more sensitive variable that would express the rainfall energy. Dexter (1977), Johnson *et al*. (1979), Steichen (1984), and Mannering *et al*. (1966) found a strong relationship between rainfall kinetic energy and soil aggregate decay.

Different techniques are used to measure soil surface roughness. Allmaras *et al*. (1966) developed a random roughness index (RR) to characterize soil surface roughness due to aggregates.

RR is based on the standard error of the adjusted natural log transformed surface elevation. Before computation of this index, the effects of slope and oriented roughness (OR) are removed.

Potter *et al*. (1990) developed a microrelief index based on the shelter angle concept. Shelter angle is defined as the maximum angle from the horizontal between measured elevation points within a 0.3-m distance on the soil surface. They calculated shelter angles for 800 points within a 1-m² area and determined their cumulative distribution as an index of surface roughness (known as Cumulative Shelter Angle Distribution, CSAD).

Potter and Zobeck (1990) fitted the Weibull function (Johnson and Kutz, 1970) to the CSAD as follows:

$$F = 1 - e^{\left(-\frac{S}{B}\right)^C} \qquad \textbf{(1)}$$

where

F	=	cumulative fraction of the surface
S	=	shelter angle, degrees
B and C	=	regression coefficients determined by non-linear least squares fit.

The B coefficient, or scale factor, increases with greater roughness and may be used as a soil surface roughness index.

Saleh (1993) developed a simple but efficient method to measure soil surface roughness using a high speed roller chain. This method is based on the principle that when a chain of given length (L1) is placed across a surface, the horizontal distance between chain ends (L2) decreases as the roughness increases. Soil surface roughness (C_r) is calculated using the L2/L1 ratio as follows:

$$C_r = \left(1 - \frac{L2}{L1}\right) \times 100 \quad . \qquad \textbf{(2)}$$

The past studies on soil surface roughness decay are limited to soil aggregates. Generally the decay rate obtained for aggregates has been used for ridges; however, field observations indicate that ridges decay at a totally different rate than that of aggregates. Therefore, a different set of equations describing the decay of ridges is needed.

Decay of surface roughness has been studied using rainfall simulators. Most simulated rain storms have a linear kinetic energy/ rainfall intensity relationship while such relationships from natural rainstorms are non-linear. Therefore, a roughness decay study under natural rainfall is needed.

This study was conducted to develop predictive equations to estimate soil aggregate and ridge decay from rainfall amount and storm erosivity and soil properties.

METHODS AND MATERIALS

Field Preparation:
The field study was conducted from January through September, 1992 on an Amarillo fine sandy loam located in Howard County, Texas (Table 1, soil #1).

Half of the field was bedded with a lister which created 0.3-m high ridges with 1-m spacing and medium-to-large size aggregates (less than 0.12 m in diameter). The other half of the field was moldboard plowed which created a surface with no profound ridges but with large aggregates (less than 0.2 m in diameter).

Field Soil Surface Roughness Measurement:
Soil surface elevation was measured after each tillage operation and after each rainfall of at least 20 mm using a pin-type soil microrelief meter (20 rows, 50 mm apart by 40 pins/row, 25 mm apart to give a grid of 800 surface elevations). The measurements were made along a 1-m transect perpendicular to the tillage direction. There were 3 sets of height readings ($800/m^2$) for the listed portion and 3 sets for the plowed portion of the field.

Soil surface elevations were corrected for slope and were then used to calculate the Weibull scale factor, B (Potter *et al*. 1990). The coefficient B which was calculated from measurements perpendicular to the ridges was due to ridges and aggregates and expressed as oriented roughness (B_{per}). The coefficient B which was calculated from measurements parallel to the ridges was due to aggregates and expressed as B_{par}.

Field Rainfall measurement:
Rainfall amount was recorded every 10 minutes by a rainfall gauge connected to a data logger. Equations **(3)** - **(6)** from Wischmeier and Smith (1958) and Foster *et al*. (1981) were used to calculate storm erosivity for each rainfall event using 10 minute rainfall data.

$$EI = (E * I_{30}) \tag{3}$$

where

EI = storm erosivity, *MJ-mm-ha^{-1}-hr^{-1}*
I_{30} = maximum 30-min rainfall intensity, *mm/hr*
E = total storm kinetic energy, *MJ-ha^{-1}*, which is obtained by:

$$E = \sum_{k=1}^{n} E_r \Delta V_r \tag{4}$$

where

n = number of 10-minute rainfall intervals
ΔV_r = rainfall amount during 10-minute interval, mm
E_r = rainfall energy, *MJ-ha^{-1}-mm^{-1}*, for each 10-minute rainfall interval which is computed from the following equations.

$$E_r = 0.119 + 0.0873 \log_{10}(i_r) \tag{5}$$

$$i_r \leq 76 \text{ mm-hr}^{-1} \quad .$$

$$E_r = 0.283 \tag{6}$$

$$i_r > 76 \text{ mm-hr}^{-1} \quad .$$

I_{30} was obtained by selecting the highest 30-minute intensity during the storm event.

Rainfall Simulator Experiments:
Soil aggregates (less than 0.1 m in diameter) were collected from 16 sites including the field study site. Soils ranged from fine sandy loam to clay (Table 1) and organic matter content varied from 0.41 to 3.27 percent. Particle size distribution was measured by the pipette method (Day, 1965). Organic carbon was determined by the chromic oxidation method (Peech *et al*., 1947). Soil aggregates for each soil were placed randomly on three 0.2 by 0.5-m porous trays. A total of 41.7 mm of water was applied to each tray at the rate of 27.8 mm hr^{-1} with an average kinetic energy of 25.0 J m^2 mm^{-1} during three simulated rainfall events. The soil aggregate roughness was measured by the chain method (Saleh, 1993) before and after each rainfall event.

1. A 0.01 m linked roller chain (ANSI 35 riv. type) with a length of 1 meter (L1 = 1 m) was very carefully laid on the top of aggregates.
2. A caliper rod was used to read the linear distance (L2).
3. Equation (2) was used to calculate C_r caused by random roughness (C_{rr}).

RESULTS AND DISCUSSION

Field Study:
Tables 2 and 3 show the summary of data obtained from the field experiment. Average annual rainfall at this study site is 487 mm. However, during this study about 678 mm of rainfall was recorded. The ratio of calculated EI per unit of rainfall increased from 0.62 in January to 11.5 in June, indicating more intense rainfall during the warmer season (Table 2).

Smaller aggregates in the listed field decayed at a slightly higher rate than that of the moldboard plowed field. Soil surface aggregates of both fields decayed after 500 mm of rainfall.

Equation (7) was obtained from regressing the natural log of RRR (B_{par} after rainfall / initial B_{par})(average of three replications) and cumulated EI (CUMEI, Mj-mm/ha-hr) for both tillage treatments (Table 3, Fig. 1):

$$RRR = e^{[-0.0012CUMEI]} \qquad \textbf{(7)}$$

$$R^2 = 0.94, P<0.001 \quad .$$

A similar but less significant relationship was obtained between natural log of RRR and cumulated rainfall (CUMR, mm) (R^2 = 0.71, P<0.001) (Table 3, Fig. 2):

$$RRR = e^{[-0.005CUMR]} \qquad \textbf{(8)}$$

$$R^2 = 0.71, P<0.001 \quad .$$

Comparing equation **(8)** to equation **(7)** indicates that CUMR did not describe the change in B_{par} during the first part of season as well as CUMEI (Figs. 1 and 2). Because of lower intensity rainfall during the early season (January through March) soil aggregate decay per unit of rainfall was much lower than later in the season (Fig. 2). Consequently, if only the rainfall amount was used as the driving parameter for soil aggregate decay, the decay rate for low intensity rainfall might be over-estimated.

CUMEI and CUMR had similar effects on ridge decay (ORR)(Table 2, Figs. 3 and 4). Figures 1 and 2 show that RR had decayed completely for both sections of the field by 3113 units of EI (500 mm of rainfall) while 48% of OR in the listed field remained after the total of 4787 units of EI (710 mm of rainfall) (Figs. 3 and 4). Because of the lower decay rate, ridges perpendicular to erosive wind would be better than aggregates to reduce erosion when surface roughness is used for erosion control, especially for high rainfall and irrigated lands. The first 25% of B_{per} decayed at almost an equivalent rate to the decay rate of the first 25% of B_{par} then the B_{per} decay rate decreased significantly. This was because of the rapid decay of aggregates covering the ridges. After aggregates dissipated, ridges became very stable and decayed at a slower rate.

Equations (9) and (10) were obtained by regressing the natural log of ORR (B_{per} after rainfall / initial B_{per}) on CUMEI or CUMR, respectively.

$$ORR = e^{[-0.05CUMEI^{0.31}]} \qquad \textbf{(9)}$$

$$R^2 = 0.99, P < 0.01 \quad .$$

$$ORR = e^{[-0.017CUMR^{0.567}]} \qquad \textbf{(10)}$$

$$R^2 = 0.98, P < 0.01 \quad .$$

In some parts of the United States (*e.g*. Northwest) rain falls with low intensity, whereas in other parts (*e.g*. Southeast) rainfall intensity occurs at much higher rate. To capture the effect of both rainfall amount and intensity, equation (11) was obtained from the regression of RRR on CUMEI and CUMR.

$$RRR = e^{[-0.0009 CUMEI - 0.0007 CUMR]} \quad \textbf{(11)}$$

$R^2 = 0.95, P < 0.01$.

Equation (12) was obtained when the natural log of ORR was regressed on CUMEI and CUMR.

$$ORR = e^{[-0.025 CUMEI^{0.31} - 0.0085 CUMR^{0.567}]} \quad \textbf{(12)}$$

$R^2 = 0.99, P < 0.01$.

Rainfall Simulator Study:
Application of the equations (11) and (12) is limited to those soils similar to the soil in the field study. To use these equations for other soils, the roughness decay factor (DF) was obtained by computing the ratio of RRR from soils #2 through #16 (Table 1) to that of soil #1 (field study soil). DF indicated that the soil aggregate stability was strongly related to clay and OM content (Fig. 5). For soils with less clay and OM than that of soil #1, DF was greater than 1.0 and for soils with higher clay and OM, DF was less than 1.0. The following function was fit to DF using the clay and OM content of tested soils as independent variables (Fig. 5).

$$DF = e^{[0.943 - 0.07 CLAY + 0.0011 CLAY^2 - 0.674 OM + 0.12 OM} \quad \textbf{(13)}$$

$R^2 = 0.92, P < 0.01$

where

CLAY = clay content, %
OM = organic matter, %.

Soil aggregate stability increased with clay content to 32% and organic matter to 2.7% and then decreased with greater amounts of clay or organic matter (Fig. 5). Potter (1990a) found similar results. Soil aggregates with higher clay content (*e.g*. soil #16) broke down as rapidly as sandy soils. Soil aggregates with low clay content (*e.g*. soil #2) broke down to erodible size particles (less than 0.001 m) whereas aggregates with higher clay content broke down to larger (less than 0.02 m), more stable aggregates.

In order to use equations (11) and (12) for other soil types, DF was inserted in these equations as follows:

$$RRR = e^{[DF(-0.0009CUMEI - 0.0007CUMR)]} \tag{14}$$

$$ORR = e^{\left[DF\left(-0.025CUMEI^{0.31} - 0.0085CUMR^{0.567}\right)\right]} \tag{15}$$

In equations (14) and (15) DF affects the rate that RRR and ORR change based on soil clay, organic matter content, rainfall amount, and rainfall erosivity index.

Validation:
Two sets of data from the literature were selected to test equations (11) and (14) predicting soil aggregates decay.

Gilly and Kottwitz (1995) conducted a rainfall simulator study on a Sharpsburg soil (Fine, montmorillonic, mesic Typic Agriudolls). Sand, silt, clay, and organic matter of this soil were approximately 5, 55, 40 and 1.89% respectively. Six tillage treatments provided a range of surface roughness conditions (Table 4). Simulated rainfall amounts of 35, 75, 150, and 300 mm were applied at 25 mm hr^{-1} with an average kinetic energy of 27.5 J m^{-2} mm^{-1} over two consecutive days. Surface elevations were measured and random roughness (RR) was calculated by the Allmaras *et al*. (1966) method. The rainfall information was used to calculate EI (Table 4). DF by equation (13) for the Sharpsburg soil was 0.39. Table 4 and Fig. 6 show that the RR predicted by equation (14) and those measured by Gilly and Kottwitz (1995) are close ($R^2 = 0.93$, $P<0.001$). However, RR predicted by equation (11), without DF, did not match as well ($R^2 = 0.75$, $P<0.001$) (Table 4 and Fig. 6). This is because of the higher clay and OM contents in the Sharpsburg soil than in the soil used during the field study. Therefore equation (11) over-estimated the RR decay for this soil, and once DF was included (Eq. 14) the RR prediction improved significantly.

Potter (1990b) measured soil surface random roughness of five soils before and after simulated rainfall (5 to 80 mm). Simulated rainfall was applied at 58 mm/hr with an average kinetic energy of 27.5 J m^{-2} mm^{-1} for the time required to apply 5, 10, 20, 40, and 80 mm of water. The rainfall information from Potter (1990b) was used to calculate EI (Table 5). Surface microrelief was measured and used to calculate RR using the Allmaras *et al*. (1966) method. Predicted RR values by equation (14) and those measured by Potter (1990b) matched reasonably well ($R^2 = 0.85$, $P < 0.001$)) (Table 5 and Fig. 7). However, once again the predicted RR from equation (11) without the DF factor resulted in under or over estimating RR for soils with a different clay or OM content.

Differences among predicted RR and RR measured by Gilly and Kottwitz (1995) and Potter (1990b) could be due to roughness measurement techniques. They used the Allmaras *et al*. (1966) method to express RR, whereas in this study random roughness was described as the Weibull coefficient B and C_r (obtained from the chain method). Nevertheless, comparisons show that equation (14) was capable of predicting RR after rainfall for different soils and aggregates of various sizes.

Because of lack of data available in the literature on ridge decay, a cooperative study is in progress to obtain field data to test equations predicting ORR.

SUMMARY AND CONCLUSIONS

Rainfall amount and EI cause soil aggregates and ridges to decay at different rates. This study was conducted to evaluate the decay of soil aggregates and ridges by natural rainfall amount and EI. This study included field and rainfall simulator experiments. During the field experiment a fine sandy loam soil, located in West Texas, was tilled by two tillage implements (a lister and moldboard plow). Soil surface roughness was measured before and after each rainfall event.

The field study showed that computed EI per mm of rainfall increased from 0.62 in January to 11.5 in June, indicating changes in rainfall characteristics throughout the year. Rainfall erosivity index (EI) was a better predictor of soil aggregate decay than rainfall amount. However, ridges with aggregates decayed at similar rates by either EI or rainfall amount. Soil aggregates decayed more rapidly than ridges. Thus, ridges are superior to aggregates for controlling erosion over extended period, especially for high rainfall and irrigated lands. Equations were obtained to predict soil aggregate and ridge decay from CUMEI or/and CUMR for the soil used during the field study; however, these equations were not applicable to other soils. Therefore, the decay factor (DF) was developed during the rainfall simulator study based on aggregates of 16 soils (ranging from fine sandy loam to clay) to modify the predictive equations obtained from field study for other soil types. The equations estimating the decay of soil aggregates were tested by data obtained from Gilly and Kottwitz (1995) and Potter (1990b) studies. Predicted RR values by equation (14) and those measured by Gilly and Kottwitz (1995) and Potter (1990b) matched reasonably well (R^2 = 0.93 and 0.85 respectively, $P < 0.001$)). However, the predicted RR from equation (11) (without DF factor) resulted in under- or over-estimating RR for soils with different clay or OM content.

Because of lack of available data on ridges decay, equations regarding decay of ridges were not tested. Currently a cooperative study is in progress to obtained field data to test equations predicting ridge roughness decay.

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Table 1. Properties of tested soils.

Soil Number	Soil Series	Sand %	Silt %	Clay %	Organic matter %
1	Amarillo fine sandy loam	75.8	12.6	11.6	0.52
2	Amarillo loamy fine sand	79.8	12.2	8.0	0.41
3	Parshal fine sandy loam	62.6	25.6	11.8	1.70
4	Amarillo fine sandy loam	80.0	7.0	13.0	0.29
5	Amarillo sandy loam	71.0	14.8	14.2	1.07
6	Amarillo sandy loam	68.4	15.6	16.0	0.73
7	Haver loam	34.9	45.1	20.0	1.99
8	Temvik Wilon silt loam	26.3	53.7	20.0	3.27
9	Weld loam	36.0	42.0	22.0	1.08
10	Olton sandy clay loam	54.7	21.3	24.0	2.44
11	Olton sandy clay loam	48.7	28.0	25.3	1.13
12	Pullman loam	23.9	52.0	24.0	1.89
13	Sherm clay loam	34.5	37.8	27.7	1.45
14	Acuff sandy clay loam	49.6	21.5	28.9	1.25
15	Haney clay	18.7	32.0	49.3	1.90
16	Huston Black clay	4.8	39.0	56.2	2.10

Table 2. Monthly rainfall characteristics during the study.

Month	Rainfall *mm*	EI *Mj-mm/ha-hr*	EI/Rainfall
January	39.1	24.2	0.62
February	90.2	182.7	2.03
March	6.3	5.1	0.8
April	45.2	56.5	1.25
May	204.8	1310.1	6.4
June	133.6	1541.2	11.5
July	32.3	193.3	5.99
August	158.9	1408.1	8.85

Table 3. Data summary of field experiement.

DATE	CUMR *mm*	CUMEI *Mj-mm /ha-hr*	------------------------Listed------------------------						----------Plowed----------		
			B_{per}	SDV	B_{par}	SDV	RRR *fraction**	ORR *fraction**	B_{per}	SDV	RRR
01-10-92	0	0	34.48†	4.90	11.35‡	1.51	-	-	13.31†	0.67	-
01-24-92	19.3	16.9	30.03	2.52	10.15	0.58	0.89	0.87	12.05	0.69	0.91
03-02-92	127.0	206.9	27.29	0.74	8.38	0.15	0.74	0.79	11.44	1.19	0.86
04-13-92	176.6	268.6	25.99	0.75	6.64	0.57	0.56	0.75	10.43	1.44	0.76
06-05-92	384.3	1578.5	20.79	1.32	2.01	0.46	0.18	0.60	3.15	1.70	0.22
06-16-92	504.6	3113.5	18.72	1.42	0	0	0	0.54	0	0	0
08-07-92	561.8	3378.8	19.21	1.72	0	0	0	0.55	0	0	0
08-17-92	616.1	3977.1	19.06	1.68	0	0	0	0.55	0	0	0
08-28-92	662.4	4304.8	17.98	1.20	0	0	0	0.52	0	0	0
09-08-92	709.4	4786.9	16.70	1.18	0	0	0	0.48	0	0	0

† Initial B_{per} (perpendicular)
‡ Initial B_{par} (parallel)
* Fraction of roughness on 01-10-92

Table 4. Measured random roughness decay by Gilly and Kottwitz (1995) and predicted by equations (11) and (14).

Tillage Operation	CUMR *mm*	CUMEI *Mj-mm/ha-hr*	Measured RR *mm* †	Predicted RR (Eq. 11) *mm*	Predicted RR (Eq. 14) *mm*
Anhydrous Ammonia	0	0	7.5		
	35	240	7.6	5.9	6.7
	75	516	5	4.5	6.2
	150	1031	5.7	2.7	5.1
	300	2062	2.8	1.0	3.4
Chisel Plow	0	0	23.6		
	35	240	14.2	18.4	21.5
	75	516	12.4	14.2	19.4
	150	1031	10.8	8.5	15.8
	300	2062	8.8	3.1	10.6
Disk	0	0	14.3		
	35	240	10.8	11.2	13.1
	75	516	10.5	5.6	11.8
	150	1031	9.8	5.2	9.6
	300	2062	6.5	1.9	6.5
Field Cultivator	0	0	9.9		
	35	240	9.1	7.7	9
	75	516	5.8	5.9	8.1
	150	1031	5.1	3.6	6.6
	300	2062	3.5	1.3	4.5
Moldboard Plow	0	0	34.2		
	35	240	26.3	24.3	31.1
	75	516	23.9	20.5	26.0
	150	1031	22.2	12.3	22.8
	300	2062	15.6	4.5	15.4
Planter	0	0	5.6		
	35	240	4.4	4.4	5.1
	75	516	3.2	3.4	4.8
	150	1031	4.2	2.0	3.7
	300	2062	4.0	0.6	2.5

† Average of two replications.

Table 5. Measured random roughness decay by Potter (1990b) and predicted by equations (11) and (14).

Soil	Cumulated Rain *mm*	Cumulated EI *Mj-mm/ha-hr*	Measured RR *mm*	SDV	Predicted RR (Eq. 11) *mm*	Predicted RR (Eq. 14) *mm*
Amarillo LFS	0	0	23.3	4.4		
Clay = 8%	5	67	19.5	5.2	22	21.7
OM = 0.34%	10	134	16.1	2.9	20.5	19.8
DF = 1.27 †	20	268	14.6	2.9	18.2	17
	40	536	9.3	1.5	14.2	12.4
	80	1072	no data	no data	8.5	6.5
Amarillo FSL	0	0	31.2	5.7		
Clay = 15%	5	67	28.7	7.3	29.3	29.6
OM = 0.47	10	134	25.6	6.4	27.2	27.8
DF = 0.86 †	20	268	24.6	2.3	24.5	25.3
	40	536	20.5	3.6	18.9	20.3
	80	1072	19.1	4.5	11.7	13.4
Acuff FSL	0	0	26.4	2.7		
Clay = 19%	5	67	24.6	2.1	24.6	25.3
OM = 0.86%	10	134	27.3	3.6	24	24.9
DF = 0.61 †	20	268	19.6	1.4	20.6	22.7
	40	536	16.4	1.9	16.1	19.5
	80	1072	15.3	0.7	9.9	14.5
Portales FSL	0	0	12.7	1.8		
Clay = 13%	5	67	8.4	1.5	11.8	11.9
OM = 0.57%	10	134	9.6	1.5	11.1	11.3
DF = 0.88 †	20	268	6.8	1.6	9.9	10.2
	40	536	8.0	2.2	7.4	8.2
	80	1072	6.2	1.0	4.7	5.3
Roscoe C	0	0	31.8	9.5		
Clay = 52%	5	67	31.2	1.1	29.9	30.8
OM = 2.16%	10	134	24.2	5.3	27.7	29.6
DF = 0.52 †	20	268	20.9	7.4	24	27.5
	40	536	29.4	1.2	19.6	24.5
	80	1072	20.3	7.4	11.6	18.8

† DF is calculated using equation 13.

Figure 1. B_{par} after/initial B_{par} ratio (RRR) as related to cumulative EI (CUMEI).

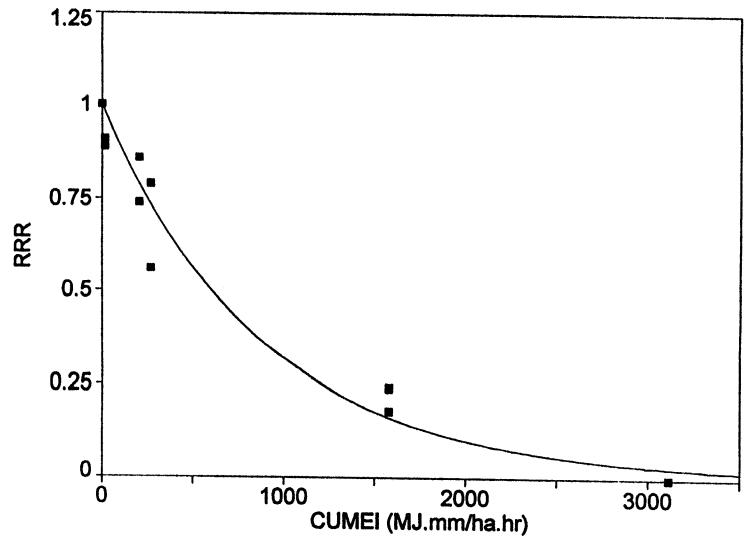

Figure 2. B_{par} after/initial B_{par} ratio (RRR) as related to cumulative rainfall (CUMR).

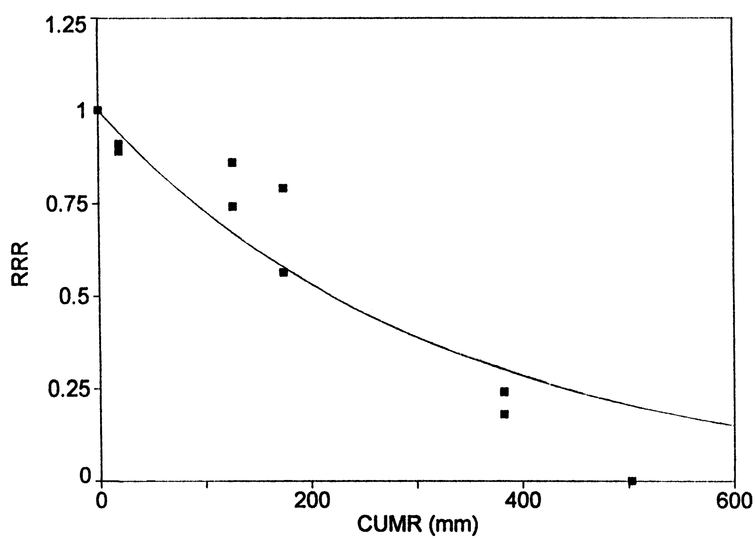

Figure 3. B_{per} after/initial B_{per} ratio (ORR) as related to cumulative EI (CUMEI).

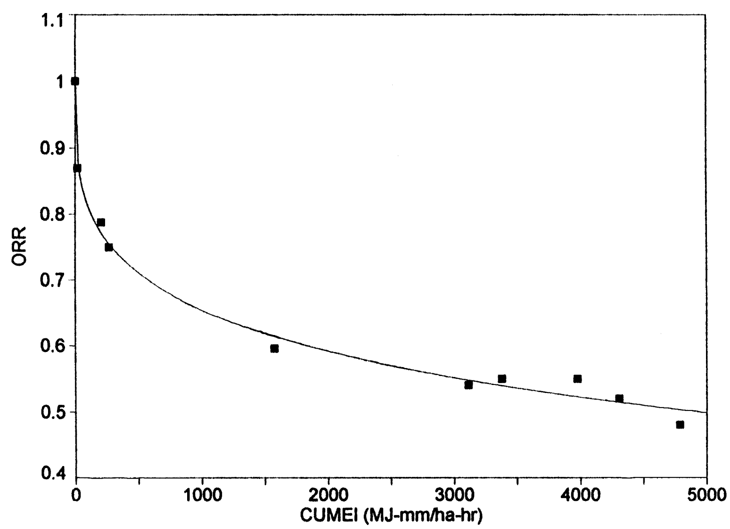

Figure 4. B_{per} after/initial B_{per} ratio (ORR) as related to cumulative rainfall (CUMR).

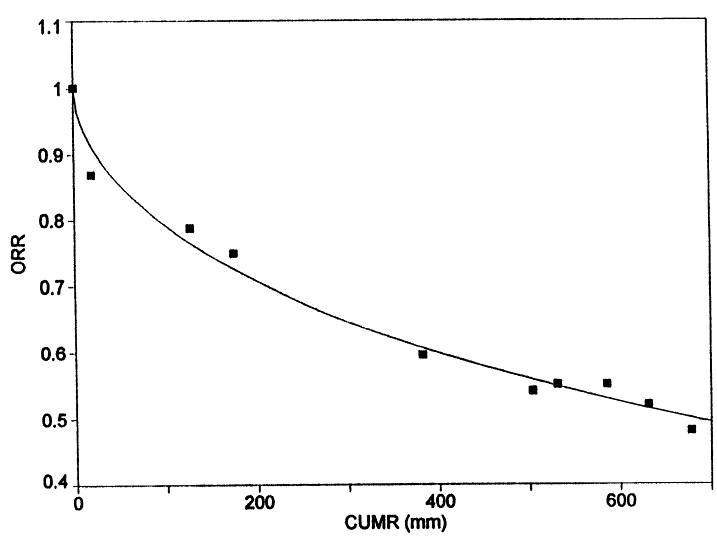

Figure 5. Decay factor (DF) as related to soil, clay, and organic matter content.

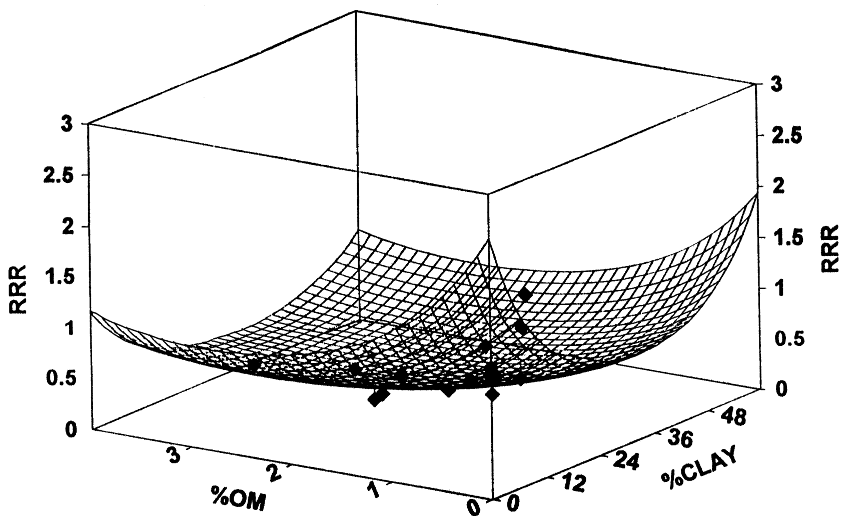

Figure 6. Measured random roughness decay by Gilly and Kottwitz (1995) and predicted by equations (11) and (14).

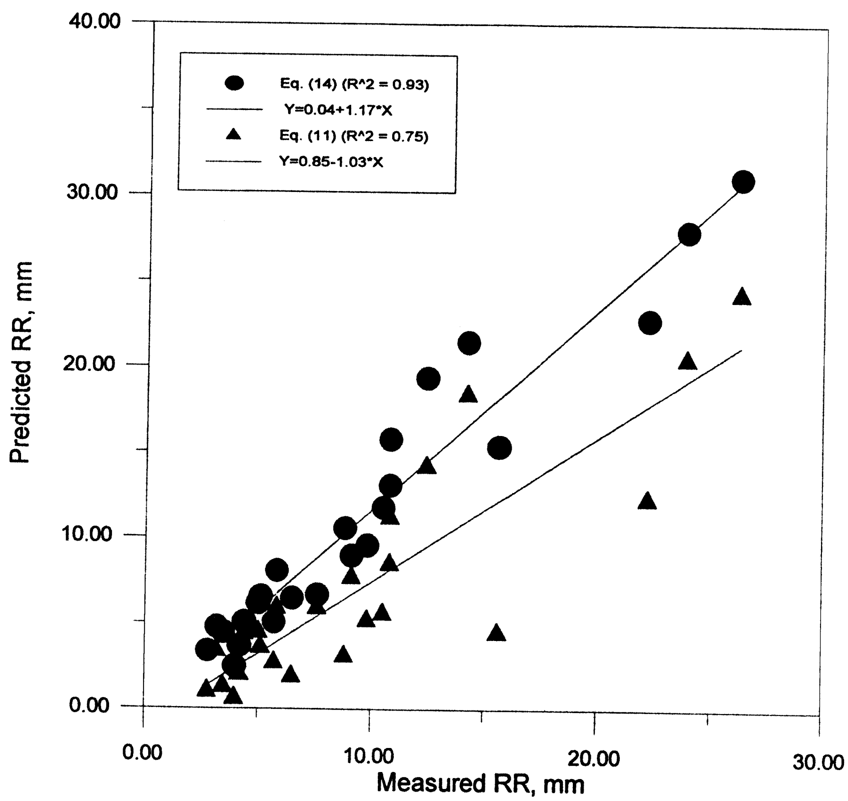

Figure 7. Measured random roughness decay by Potter (1990b) and predicted by equations (11) and (14).