Ref. 30
Area 6

707653

Health Physics Pergamon Press 1965. Vol. 11, pp. 1333–1340. Printed in Northern Ireland

MOVEMENT OF ^{137}Cs BY RUNOFF, EROSION AND INFILTRATION ON THE ALLUVIAL CAPTINA SILT LOAM*

A. S. ROGOWSKI and TSUNEO TAMURA
Health Physics Division, Oak Ridge National Laboratory, Oak Ridge, Tennessee

(*Presented by* A. S. ROGOWSKI)

Abstract—Five millicuries of ^{137}Cs were applied in the form of spray to the 5-m^2 plots of Captina soil in Tennessee under bare, clipped meadow, and tall meadow cover conditions. During the initial 81-day period agreement was observed between predicted and experimental soil loss. A linear relationship on a full log scale was found between the soil and ^{137}Cs loss.

On the plots with vegetation, it was found that practically all of the ^{137}Cs applied to the areas covered with vegetation was initially on the plant and litter material. The leaching of ^{137}Cs from the vegetation began to level off towards the end of the study period (20.5 cm of rain). At the end of the 81-day period, the bare plot had lost 11.9 per cent of the cesium while the clipped meadow and tall meadow plots had lost 5.1 per cent and 2.6 per cent of their cesium, respectively.

INTRODUCTION

STUDIES of fission product movement by runoff and erosion have been concerned with fallout contamination, particularly with attention to radiostrontium.[1,2] MENZEL,[1] working with soils from Wisconsin and Georgia, found that up to thirty times more ^{90}Sr was associated with soil particles in runoff than in the original soil. He noted that 25 per cent of the ^{90}Sr deposited at a given time by fallout can be lost by runoff and erosion from plots in corn and oats in Wisconsin. FRERE and ROBERTS[2] concluded that as much as two-thirds of the ^{90}Sr deposited by fallout had been lost by runoff and erosion from a cultivated watershed in Ohio. GRAHAM[3] also noted the importance of seasonal variations in his studies on a Missouri soil. He reported that more ^{85}Sr and ^{131}I was lost in the 1961 season than in the 1960 season and inferred that the difference was due to the higher soil moisture conditions during 1961 which increased runoff.

Very little information is available on the movement of ^{137}Cs by runoff and erosion; indeed the high sorption of this element by most soils suggests immediate fixation and stabilization in the surface soil.[4,5] It was felt that the concentration of ^{137}Cs at or very near the surface of the soil would contribute to movement by runoff and erosion because the surface particles are more susceptible to movement by these mechanisms. Furthermore, the use of long-lived radiocesium would permit following the behavior of radionuclide over a long time span.

In this paper the movement of ^{137}Cs on a Captina soil in East Tennessee under different cover conditions is reported for the 81-day period after the spray application. The higher rate of application than those used by GRAHAM,[3] the different soil and plant characteristics, and the different rainfall pattern in East Tennessee suggested the need for close attention to the movement of this radionuclide during the early stages after application.

METHODS AND MATERIALS

Soil description

The experimental area is located on the alluvial plain of the north bank of the Clinch River at the Oak Ridge reservation. The soil belongs to the Captina series which occupies low to intermediate areas along the Clinch River. These areas were subject to flooding during high flood crests prior to the TVA flood control

* Research sponsored by the U.S. Atomic Energy Commission under contract with the Union Carbide Corporation.

REPOSITORY Oak Ridge Energy Systems
COLLECTION
BOX No.
FOLDER

1024859

A-00059
Human Subjects Project

program. The alluvial deposits are a mixture of materials derived from sandstone, limestone and shale. Sandstone and shale predominate in the upper 5 ft of the deposit. During exploratory drilling, coarse, sandy material was encountered in the experimental area at about 12 ft, containing the permanent water table at approximately the level of Clinch River.

Figure 1 shows a profile of Captina silt loam. In the experimental area about 4 in. of highly permeable (8 in. water/h) top soil (A_p) rests on a massive 4-in.-thick former plow pan (A_3). Water movement through this A_3 layer is restricted and takes place largely through the root cracks at the rate of 1.5 in./h. Below this layer are the B_1 and B_2 horizons with a vertical permeability of 0.3 in./h and horizontal permeability of 0.2 in./h. Below B_2 and starting at 21–24 in., a fragipan layer occurs. Although occasionally highly permeable sand lenses appear in the B_3M_1 portion of the fragipan, the soil is very massive and virtually impermeable (0.02 in./h) below the 40-in. depth (B_3M_2). As a result of the fragipan layer, waterlogged conditions prevail in the upper 4 ft of the profile during most of fall, winter and spring. The composite infiltration rate of up to 15 in./day and drainage rate of 4 in./day has been observed experimentally under field conditions. With a temporary water table close to the ground surface occurring during the late fall, winter and spring, the soil is subject to erosion, even by minor storms during these seasons.

Experimental area description

The experimental portion of the area covered with a mixture of crabgrass and fesc with crabgrass predominating. If a poi sampler[6] is used, there is on the average 73 p cent surface plant cover and 8.9 per cent bas plant cover with 300–500 g of plant materi (dry weight) per m² of surface. The slop found in the field range from 2 to 15 per cen Three experimental plots were chosen f tagging with ^{137}Cs. In the first plot the veget tion was removed (Fig. 2a); in the second pl the meadow was clipped and the litter was le on the ground (Fig. 2b); and in the thi plot the meadow was fertilized and allowed grow tall (Fig. 2c).

In Table 1 pertinent data for each plot a given, and in Fig. 3 a general view of t experimental plot locations is shown. Each the experimental plots (as shown in Fig. which was surrounded by a 2.5 × 2.5 m pe was enclosed by a 15-cm-wide metal strip su to a depth of 7 cm into the ground. A fou plot was kept in reserve for future studies. the lowest corner of each plot a runoff si was cemented in place and connected by me of a rubber hose encased in galvanized pipe the runoff pans. Each pan (also shown Fig. 3) was equipped with calibrated drums a water level recorder. A recording rain gauge runoff disposal pit (not shown in Fig. 3), an runoff transfer water pump were included a permanent part of the experimental setup.

Table 1. Effective area, slope, slope length, canopy cover, basal cover and plant matter on the dry basis on the experimental plots at the Oak Ridge National Laboratory*

Plot number and description	Effective area (m²)	Average slope (%)	Average slope length (m)	Canopy cover (%)	Basal cover (%)	Dry plan matter (g/n
1—Bare soil	5.54	2.95	2.19	0	0	0
2—Clipped meadow	5.33	4.63	2.04	74.0† 61.0 13.0	7.4	374.0‡
3—Tall Meadow	5.40	13.38	1.98	76.0	9.4	406.0§

* Effective area is contained inside the metal border strip, excluding sink.

† The first number represents total per cent of canopy cover; the second number represents total per of litter cover; and the third number represents the total per cent of plant cover.

‡ This value includes both litter and plant material. An average value on the basis of two samplings 30.7 per cent plant material and 69.3 per cent litter material.

§ Average value on the basis of three samplings.

1024860

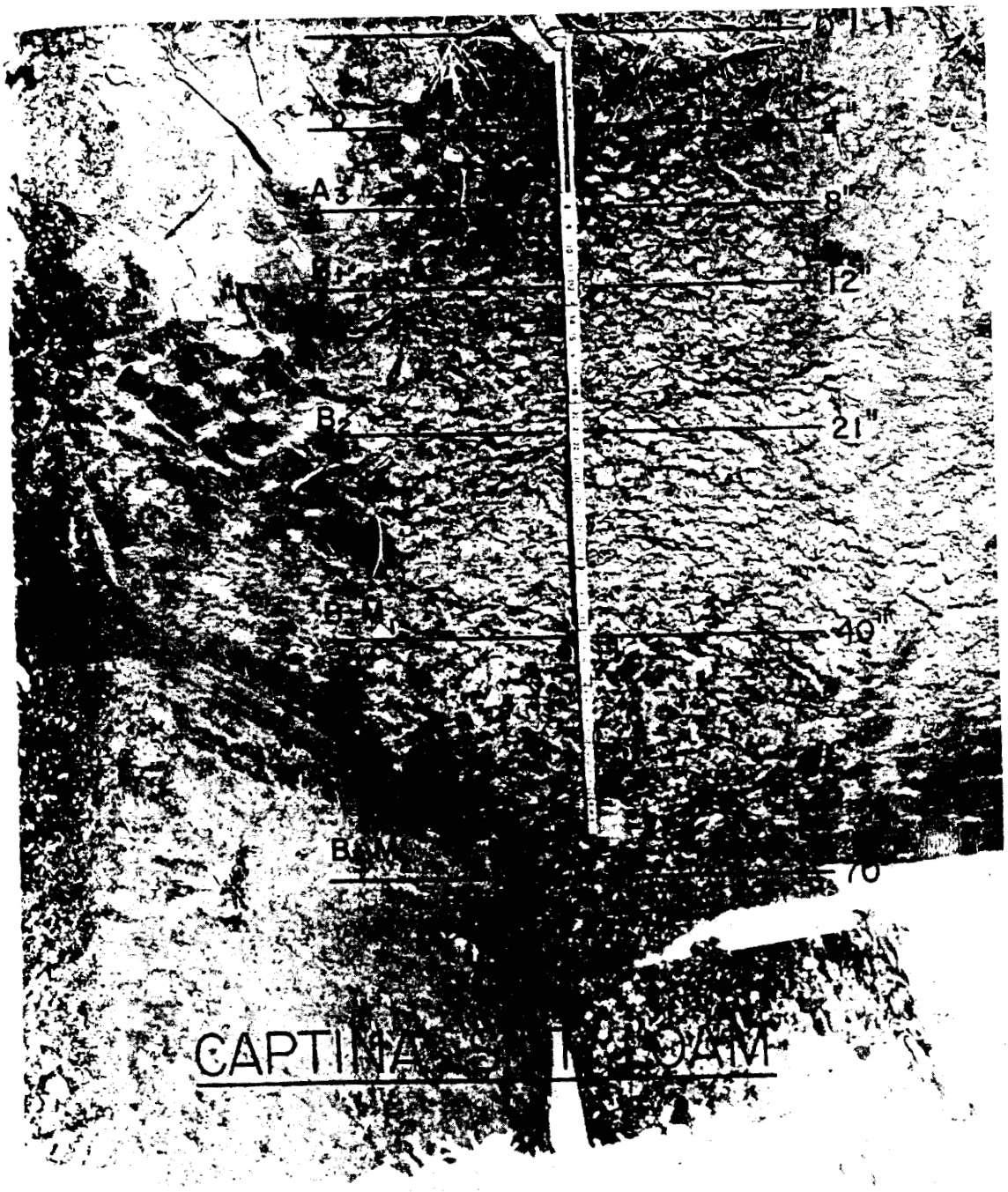

FIG. 1. Profile of Captina silt loam soil.

1024861

program. The alluvial deposits are a mixture of materials derived from sandstone, limestone and shale. Sandstone and shale predominate in the upper 5 ft of the deposit. During exploratory drilling, coarse, sandy material was encountered in the experimental area at about 12 ft, containing the permanent water table at approximately the level of Clinch River.

Figure 1 shows a profile of Captina silt loam. In the experimental area about 4 in. of highly permeable (8 in. water/h) top soil (A_p) rests on a massive 4-in.-thick former plow pan (A_3). Water movement through this A_3 layer is restricted and takes place largely through the root cracks at the rate of 1.5 in./h. Below this layer are the B_1 and B_2 horizons with a vertical permeability of 0.3 in./h and horizontal permeability of 0.2 in./h. Below B_2 and starting at 21–24 in., a fragipan layer occurs. Although occasionally highly permeable sand lenses appear in the B_3M_1 portion of the fragipan, the soil is very massive and virtually impermeable (0.02 in./h) below the 40-in. depth (B_3M_2). As a result of the fragipan layer, waterlogged conditions prevail in the upper 4 ft of the profile during most of fall, winter and spring. The composite infiltration rate of up to 15 in./day and drainage rate of 4 in./day has been observed experimentally under field conditions. With a temporary water table close to the ground surface occurring during the late fall, winter and spring, the soil is subject to erosion, even by minor storms during these seasons.

Experimental area description

The experimental portion of the area is covered with a mixture of crabgrass and fescue with crabgrass predominating. If a point sampler[6] is used, there is on the average 73 per cent surface plant cover and 8.9 per cent basal plant cover with 300–500 g of plant material (dry weight) per m^2 of surface. The slopes found in the field range from 2 to 15 per cent. Three experimental plots were chosen for tagging with ^{137}Cs. In the first plot the vegetation was removed (Fig. 2a); in the second plot the meadow was clipped and the litter was left on the ground (Fig. 2b); and in the third plot the meadow was fertilized and allowed to grow tall (Fig. 2c).

In Table 1 pertinent data for each plot are given, and in Fig. 3 a general view of the experimental plot locations is shown. Each of the experimental plots (as shown in Fig. 3), which was surrounded by a 2.5 × 2.5 m pen, was enclosed by a 15-cm-wide metal strip sunk to a depth of 7 cm into the ground. A fourth plot was kept in reserve for future studies. At the lowest corner of each plot a runoff sink was cemented in place and connected by means of a rubber hose encased in galvanized pipe to the runoff pans. Each pan (also shown in Fig. 3) was equipped with calibrated drums and water level recorder. A recording rain gauge, a runoff disposal pit (not shown in Fig. 3), and a runoff transfer water pump were included as a permanent part of the experimental setup.

Table 1. Effective area, slope, slope length, canopy cover, basal cover and plant matter on the dry basis on the experimental plots at the Oak Ridge National Laboratory*

Plot number and description	Effective area (m^2)	Average slope (%)	Average slope length (m)	Canopy cover (%)	Basal cover (%)	Dry plant matter (g/m^2)
1—Bare soil	5.54	2.95	2.19	0	0	0
2—Clipped meadow	5.33	4.63	2.04	74.0† 61.0 13.0	7.4	374.0‡
3—Tall Meadow	5.40	13.38	1.98	76.0	9.4	406.0§

* Effective area is contained inside the metal border strip, excluding sink.

† The first number represents total per cent of canopy cover; the second number represents total per cent of litter cover; and the third number represents the total per cent of plant cover.

‡ This value includes both litter and plant material. An average value on the basis of two samplings gives 30.7 per cent plant material and 69.3 per cent litter material.

§ Average value on the basis of three samplings.

1024862

1024863

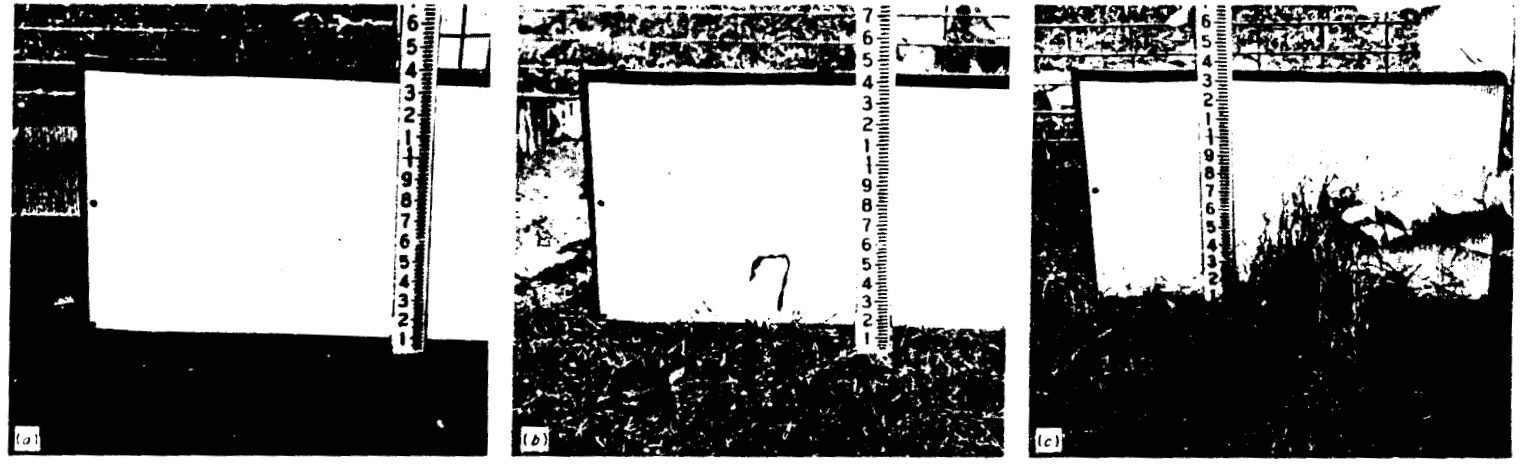

FIG. 2. Cover conditions on the experimental plots: (a) bare soil (Plot 1), (b) clipped meadow (Plot 2) and (c) tall meadow (Plot 3).

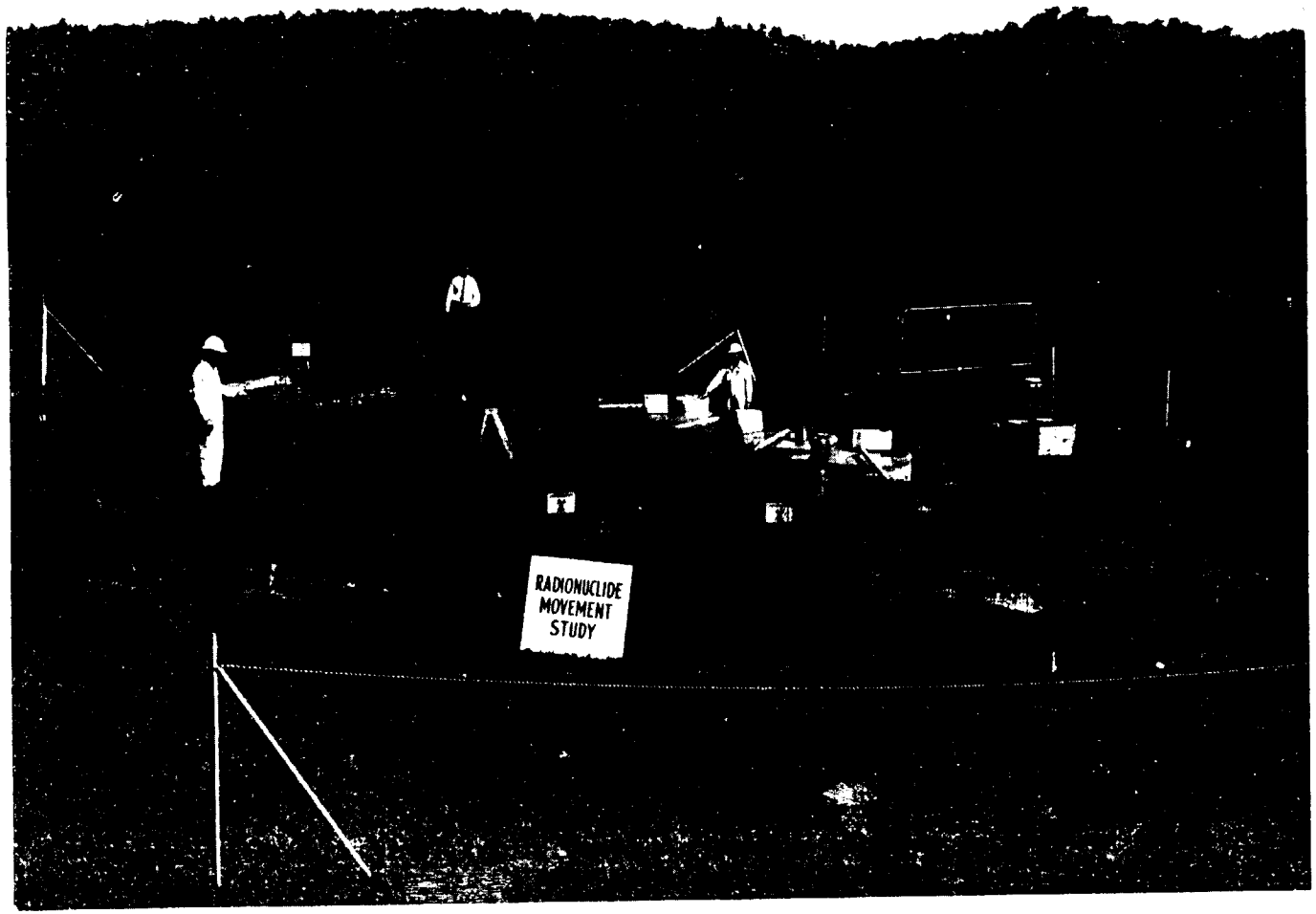

FIG. 3. View of experimental area showing plot and runoff catchment pans locations.

1024864

1024865

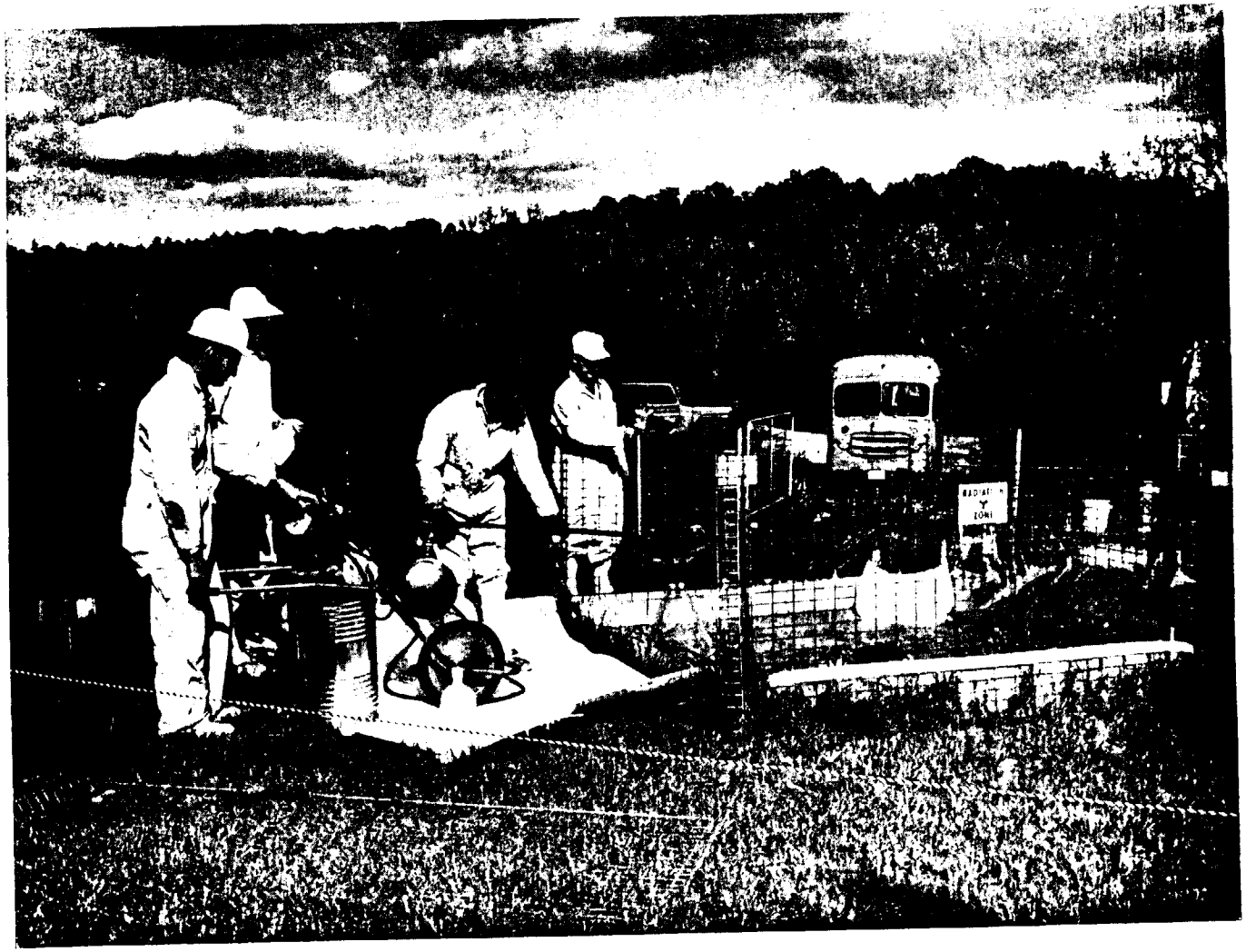

FIG. 4. Application of ^{137}Cs to an experimental plot, showing equipment used in tagging.

The information from the recording rain gauge on duration, intensity and amount of rainfall for each storm was used in computing the erosion index (*EI*) value. It was also correlated with the runoff rates, amounts and starting times obtained with the water-level recorders for each plot.

Tagging

Application of ^{137}Cs tag (Fig. 4) was carried out using a modified orchard sprayer at constant pressure of 50 psi, under the direction of H. D. WALLER, Radiation Ecology Section. Five millicuries of ^{137}Cs were diluted to 4000 ml volume in a weak HCl solution (pH 4.0). This quantity was sufficient for five complete spray passes. Alternate sprayings were made in the direction at right angles to the previous application. ^{137}Cs tag was applied under dry soil conditions. The first rain was recorded 6 days after tagging.

Sampling

After each storm the runoff collected was stirred and mixed thoroughly. Exactly 500 ml was sampled and centrifuged at 2400 rpm with 1 ml of 1 *M* $CaCl_2$. The supernate was decanted, the solids dried, weighed on the analytical balance, and multiplied by a proportionality factor to give the soil loss in grams per plot. It should be pointed out that all handling and sampling equipment consisted of polyethylene laboratory ware to prevent sorption of ^{137}Cs by glass or metal surfaces.

A further 31-ml sample was obtained and used in the ^{137}Cs loss determination. The sample was centrifuged for 15 min prior to counting on a multichannel analyzer; after the counting, sufficient $CaCl_2$ was added to make the solution 1 *M* with respect to $CaCl_2$. The flocculated clay was centrifuged and recounted. A 15-ml sample of the supernate was removed and counted separately. This counting procedure was established when it was found that the bulk of the activity was associated with the solid particles in the runoff and that the cesium associated with the particles was not significantly desorbed by addition of $CaCl_2$. The 15-ml supernate count served to verify this conclusion and also served as a check of the procedure.

RESULTS

Study period

The study period reported here covers 81 days between 20 October 1964 and 9 January 1965. In Table 2 total rainfall for the months covering the study period is given and compared with the normal rainfall for the same time. Table 3 gives maximum observed 24-h rain and its expected return period for maximum rains during the 81-day study period. Table 4 compares observed erosion index (*EI*) values for the study period with expected and maximum average annual *EI* values for the experimental area. The *EI* value is a numerical evaluation of the capacity of a specific rainfall pattern to erode soil from the unprotected fields. It is the product of rainfall energy, and its maximum 30-min intensity.[7]

Table 2. Total rainfall for months covering the study period as compared to the normal† rainfall for the same time*

	Observed rain (in.)	Normal rain (in.)	Departure from normal
October	1.94	2.82	−0.88
November	2.47	3.49	−1.02
December	4.73	5.22	−0.49
January	4.71	5.24	−0.53

* The total rainfall for 81 days of the study period was 11.69 in.

† Normal rain is for Oak Ridge local climatological data with comparative data for 1964.

Analyzing the information given in Tables 2, 3 and 4, we conclude that although the total rainfall was generally below normal during the study period, storms of higher-than-average energies and intensities were observed. It should be noted that soil loss and ^{137}Cs loss values are given for the time of year when the soil is generally in wet and water-logged condition and when the vegetation is dead.

Soil loss

In Fig. 5 actual soil loss values in g/m^2 observed on the experimental plots are plotted for each type of cover conditions against the erosion index (*EI*) value in $(ergs/cm^2)$ (cm/sec). The straight lines drawn through the experimental points represent the theoretical loci of

102486b

Table 3. Maximum observed 24-h rain and its expected return period for maximum rains during the 81-day study period

Month	Plot study (rain. in.)	Maximum observed 24-h rain: Return period* (precip. days)	Probability of occurrence† (return period)	Average number of‡ (precip. days)	Probability of occurrence§ (return period)
October	0.68	4	33 times/y	9	Twice every October
November	1.40	16	8 times/y	9	Every 2 y
December	1.86‖	30	4 times/y	13	Every 2 y
January	3.30	250	every 2 y	13	Every 19 y

* Data computed from *ORO*-99, *A Meteorological Survey of the Oak Ridge Area*, 1948–1952, Fig. 49.

† Probability of such a rain occurring again, assuming 133 precipitation days (precipitation $\geqq$ 0.01 in. of rain). See *ORO*-99, Table 18c.

‡ Data from *ORO*-99, Fig. 47c.

§ Probability of such a rain occurring again in the same month.

‖ Observed maximum intensities in December and January were 3.60 in./h for 10 min, 2.04 in./h for 5 min, and 1.80 in./h for 10 min. Return period for such intensities is equal to or less than 2 y (rainfall-intensity-duration frequency curves for Knoxville, Tennessee, published by U.S. Weather Bureau).

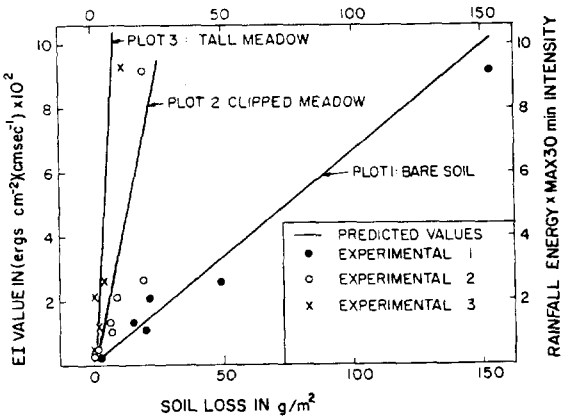

FIG. 5. Experimental soil loss as a function of erosion index (*EI*) for the bare soil (Plot 1), clipped meadow (Plot 2), and tall meadow (Plot 3). Solid lines give predicted values. Predicted curve for Plot 2 is corrected to include loss from bare soil border.

points expected for the rainfall pattern, soil type area slope, slope length and cover conditions that prevailed on the respective plots during the study period. The curves were calculated from the erosion equation given by WISCHMEIER and SMITH,[7] WISCHMEIER *et al.*,[8] WISCHMEIER,[9] and data listed in Ref. (10). For the short study period, the agreement of theoretical predictions and experimental results is considered satisfactory.

A 15-cm-wide border of bare soil surrounded Plot 2. The contribution to the soil and ^{137}Cs loss from this area was found to be considerable and was taken into account in the calculations. The theoretical predicted curve for Plot 2 in Fig. 5 represents the soil loss as a function of erosion index from the clipped meadow plot with 80 per cent of the total area covered by vegetation and 20 per cent of the total area consisting of a bare soil border strip.

Table 4. Observed erosion index (EI) *values for the study period compared with expected and maximum average annual* EI

Description	*EI* (ergs/cm²)(cm/sec)*	% of Annual
Cumulative *EI* observed: 10/20/64–1/9/65	1968	20
Cumulative *EI* expected: 10/20–1/9†	1183	12
Maximum expected: 6/1–9/1†	4872	49

* 0.473 (ergs/cm²)(cm/sec) = 1 *EI* unit in (ft-ton/acre)(in./h).

† Soil loss estimation in Tennessee. Unpublished Proceedings of Soil Loss Prediction Conference, University of Tennessee, Knoxville, Tennessee, 1959.

1024867

In Table 5 the total observed soil loss during the study period is compared with the soil loss predicted from the erosion equation given by WISCHMEIER and SMITH.[7] The erosion equation had been derived on the basis of a large number of observations with a subsequent statistical treatment of the variables. The agreement shown in Table 5 on the basis of relatively few observations is considered satisfactory.

Table 5. Observed total soil loss on the runoff plots compared with the soil loss predicted by the use of erosion equation for the study period 20 October 1964, to 9 January 1965.*

Plot Number	Description	Soil loss in grams per plot Observed	Predicted
1	Bare soil	1488	1648
2	Clipped meadow	340	282†
3	Tall meadow	93	101

* WISCHMEIER and SMITH (1958).
† Corrected for bare soil border present.

^{137}Cs *loss from soil*

In Fig. 6 cumulative ^{137}Cs loss in per cent is plotted as a function of cumulative soil loss in g/m^2 on a full log scale. The dashed lines for Plot 1, "Plot 2 plus border," and Plot 3 represent extrapolations to the very low readings (data not shown in Fig. 6) obtained during the initial runoff producing rain. For example, 1.6 g/m^2 soil loss on Plot 1 accounted for 0.006 per cent of ^{137}Cs loss. The curve for "Plot 2 less border" represents estimated loss of ^{137}Cs from the vegetation-covered portion of Plot 2. The curve for "Plot 2 plus border" represents the observed ^{137}Cs loss values from the whole plot, including the border bare soil covered strip. In Fig. 6 initial concentrations of ^{137}Cs are given. These concentrations assume a uniform application of 5 mCi of ^{137}Cs per plot and are computed using effective areas for respective plots listed in Table 1.

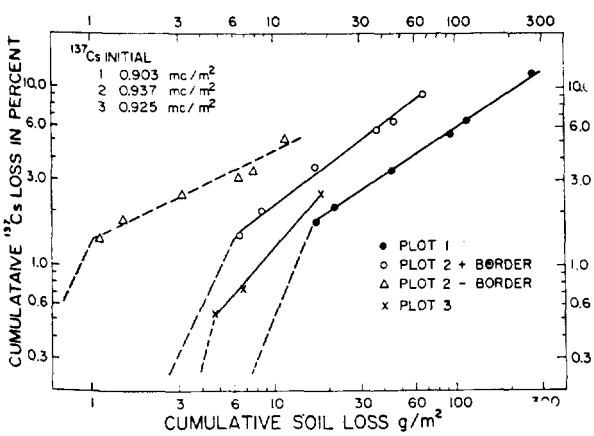

FIG. 6. Cumulative ^{137}Cs loss as a function of soil loss for the bare soil (Plot 1), clipped meadow (Plot 2, plus border), tall meadow (Plot 3) and clipped meadow corrected to exclude border (Plot 2, minus border).

Table 6. Specific concentration of ^{137}Cs in the runoff in μCi/g of soil lost for the initial and final part of the study period

Period	Specific concentration (Ciμ/g) Plot 1	Plot 2	Plot 3
October 26–December 5	0.91	2.74	2.00*
December 14–January 9	0.42	1.26	1.25

* Estimated value. No appreciable soil loss was observed on Plot 3 until 24 December 1964.

Table 6 gives average specific concentrations of ^{137}Cs in the runoff for the initial and final part of the study period. It should be pointed out that in Fig. 6 the second points on the lower part of the curve for Plot 1 and "Plot 2 plus border" and the first point of the curve for Plot 3 represent cumulative per cent of ^{137}Cs lost during the initial part of the study period (up to 5 December 1964). The relationship between the data in Table 6 and in Fig. 6 is as follows. If the solid lines in Fig. 6 for Plot 1, 2 and 3 were to be extrapolated back at the same relative slope (and not at a steeper slope shown by dashed lines in the figure), the specific concentrations for the initial part of the study period would have been 0.7, 1.8 and 0.9 μCi per g of soil for Plots 1, 2 and 3, respectively. The data in Table 6 show on the average a higher specific ^{137}Cs concentration. It is felt therefore that the extrapolations to the low values shown by dashed lines in Fig. 6 are valid and that the steeper slopes reflect a faster rate of initial loss.

1024868

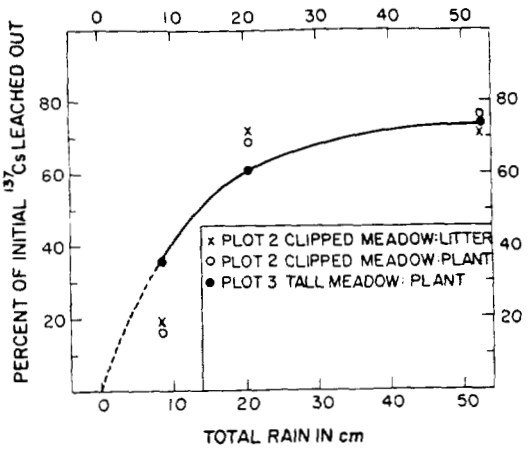

FIG. 7. Leaching loss of ^{137}Cs as a function of total rain for Plot 2 (litter) Plot 2 (plant) and Plot 3 (plant).

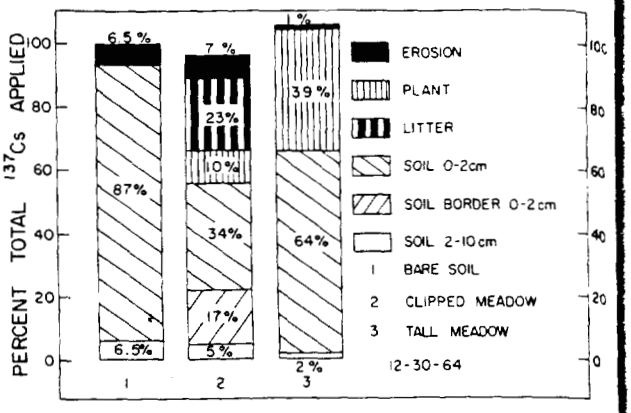

FIG. 8. ^{137}Cs mass balance for soil, litter and plant materials on the bare soil (1), clipped meadow (2) and tall meadow (3) plots. Sampling date was 30 December, 1964.

^{137}Cs loss from the plant material

After ^{137}Cs was applied on the plots with vegetation (Plot 2 and 3), it was found* that practically all of the ^{137}Cs was on the plant and litter material. The data obtained in the subsequent sampling of the vegetation are presented in Fig. 7.

On the basis that all of the ^{137}Cs was on the vegetation initially, Fig. 7 gives the per cent of ^{137}Cs leached from the vegetation as a function of total rain. The last set of points for 52.5 cm of rain was based on the samples of 22 March 1965; and, although this date extends beyond the study period, the data are included for clarity. The set of points plotted for 20.5 cm of rain was obtained on 30 December 1964. The first set of points was caclulated from data obtained by H. D. WALLER.* It appears that no leaching occurred in the litter materials after 52.5 cm of rain as compared with 20.5 cm of rain. It is possible that the apparent lack of leaching is due to the transfer of ^{137}Cs from the plant to the underlying litter material during leaching.

Mass balance

Figure 8 shows the mass balance computed on the basis of soil, litter and plant material sampling on 30 December 1964. The soil was sampled in 2-cm increments to a depth of 10 cm. Note that by 30 December 1964, most of the applied ^{137}Cs was found to be on the soil. For Plot 2 the 17 per cent value given for the bare soil border is an estimated value based on the results obtained for Plot 1. Conversely, the 34 per cent value represents the actual per cent of the total ^{137}Cs found on the soil underlying the vegetation cover. These values were computed on the basis of unit area. Furthermore, the percentages given in Fig. 8 for Plots 2 and 3 have been corrected for the amount of basal cover (Table 1).

Had the sampling been made on 10 January 1965 (after the intense storm on 9 January 1965), the erosion losses would have been 12, 9 and 3 per cent for Plots 1, 2 and 3, respectively. The mass balance shows total recovery for the bare soil on Plot 1, but is low by about 4 per cent on Plot 2 and in excess by about 6 per cent on Plot 3.

DISCUSSION

No conclusions on the long-term behavior of ^{137}Cs can be drawn on the basis of the short 81-day study period. There is, however, enough information to indicate the trends and establish two relationships to be examined in greater detail over an extended time.

The first relationship of importance is presented in Fig. 6. The data presented in Fig. 6 immediately raise the question of whether or not

* H. D. WALLER, Radiation Ecology Section, ORNL, 1964.

1024869

the straight line relationship on a full log scale between the ^{137}Cs loss and soil loss will continue until all cesium has been removed by erosion.

Given the same pattern of soil loss, values of the ^{137}Cs loss should remain the same for any period during the year. However, if any significant movement deeper into the soil profile by infiltration and through the plant roots takes place, the ^{137}Cs loss–soil relationship would reflect this change. The distribution coefficient (*Kd*), which is the ratio of adsorbed cesium per gram of soil to the unadsorbed cesium per milliliter of solution, is 3×10^4 ml/g for the A_p horizon. Since the *Kd* for ^{137}Cs of the Captina is very high, it is felt that no appreciable amount of ^{137}Cs would move into the profile by infiltration. The relationship shown for Plot 1 in Fig. 6 should therefore hold for any time during the year. Any seasonal change in the relationship for Plot 2 and Plot 3 would suggest the translocation by plant roots of ^{137}Cs into the deeper horizons of the soil profile.

The movement of ^{137}Cs into the soil profile is relatively minor. On the basis of mass balance computations, given in Fig. 8, more than 90 per cent of the ^{137}Cs associated with the soil was found to be in the upper 2 cm of the profile at the sampling time. It is felt that a large part of ^{137}Cs found below the 2 cm depth could have been due to the inadvertent contamination by the sampling tools. Thus the relationship describing the loss of ^{137}Cs by erosion becomes the principal mode of transfer of this radionuclide and acquires a special significance.

The second relationship of importance concerns the leaching of ^{137}Cs from vegetation by rain. According to the data presented in Fig. 7, the loss by rainfall leaching begins to level off after about 20.5 cm of rain. If true, the specific ^{137}Cs concentration in the runoff from the vegetation covered plots should decrease and approximate the specific ^{137}Cs concentration in the runoff from the bare soil plot (Table 6). This decrease in the specific ^{137}Cs concentration on the vegetation covered plots should be reflected by a decrease in slope for curves of Plots 2 and 3 in Fig. 6. Data obtained after the study period indicate that the slopes of the curves of Plots 2 and 3 do tend to decrease. More data are necessary to confirm this behavior.

The difference of the specific ^{137}Cs concentration on the runoff from the bare soil (Plot 1) and vegetation covered plots (Plots 2 and 3), shown in Table 6, has raised a question about the fate of ^{137}Cs leached from vegetation. The specific ^{137}Cs concentration in the runoff from Plots 2 and 3 is about three times as large as in the runoff from Plot 1. One may postulate that ^{137}Cs leached by rain from vegetation becomes fixed on the fine fraction of the soil materials present in the runoff water during the storm without ever reaching the soil surface. Laboratory studies in progress show that about twice as much ^{137}Cs is leached from vegetation when fine soil particles are present in the leaching water as is leached by the equivalent amount of pure rain water from the same storm.

Finally, it is interesting to compare the radionuclide losses reported in this study with the findings of others. GRAHAM,[3] working in Missouri, found that the highest loss of ^{85}Sr occurred on his fallow plot, amounting to 0.097 per cent in the fall of 1960 and 0.982 per cent in the fall of 1961. The lowest loss occurred on a fescue meadow plot and amounted to 0.037 per cent in 1961. In our studies with ^{137}Cs the fallow plot (bare soil) showed a loss of 11.86 per cent, and the fescue–crabgrass meadow plot (tall meadow) showed a loss of 2.57 per cent for the study period. The differences are likely due to the higher rainfall in East Tennessee as compared with Missouri, to the higher energy and intensity rains which fell here and to the nature of the radionuclide. Faster movement of strontium downward into the profile as compared to the downward cesium[5] movement could result in a relatively lower loss of strontium by erosion. Although a steeper slope (13.4 per cent) is present in our tall meadow plot, as compared to 3 per cent in the Missouri plot, the high loss of ^{137}Cs on our clipped meadow plot (5.10 per cent) with only 4.6 per cent slope (Plot 2 less border in Fig. 6) reduces the probability that the slope factor was the only reason for the higher losses in our tall meadow plot.

FRERE and ROBERTS[2] report that one- to two-thirds of the ^{90}Sr deposited by fallout up to 1960 was lost on cultivated watershed in Ohio with an average slope of 13 per

1024810

cent. Even if the ^{137}Cs loss rate were to remain constant on our tall meadow plot, it would lose approximately 10 per cent of the radiocesium on a similar slope in about 8 months time. Further speculation is premature at this time. The widely differing results obtained by investigators on radionuclide movement strongly suggest the need to continue these studies and to define quantitatively the parameters affecting radionuclide movement by runoff and erosion.

REFERENCES

1. R. G. Menzel, *Science* **131,** 499 (1960).
2. M. H. Frere and M. Roberts, Jr., *Proc. Soil Sci. Soc. Am.* **27,** 82 (1963).
3. E. R. Graham, *Wat. Sewage Wks* **110,** 407 (1963).
4. L. Fredericksson, B. Ericksson, B. Rasmuson, B. Gahne, K. Edvarson and K. Low, *Proceedings of 2nd International Conference on Peaceful Uses of Atomic Energy, Geneva,* 1958, Vol. 18, p. 449. United Nations, New York (1958).
5. J. R. Miller and R. F. Reitemeier, *Proc. Soil Sci. Soc. Am.* **27,** 141 (1963).
6. D. Brown, Methods of surveying and measuring vegetation, *Commonwealth Bureau of Pasture and Field Crops, Bulletin* 42. Hurley, Berks (1954).
7. W. H. Wischmeier and D. D. Smith, *Trans. Am. Geophys. Union* **39,** 285 (1958).
8. W. H. Wischmeier, D. D. Smith and R. E. Uhland, *Agric. Engng.* **39,** 458 (1958).
9. W. H. Wischmeier, *Proc. Soil Sci. Soc. Am.* **24,** 322 (1960).
10. Soil loss estimation in Tennessee, Unpublished Proceedings from Soil Loss Prediction Conference. University of Tennessee, Knoxville, Tennessee (1959).

1024871