Soil Erosion Rates in West Central Saskatchewan

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ABSTRACT

Soil erosion trends and rates in five Rural Municipalities of West Central Saskatchewan are assessed using Cesium-137 as an indicator of soil redistribution within the landscape. The study area is located around Unity, and includes the Rm's of Reford, Tramping Lake, Grass Lake, Buffalo, and Round Valley. Native, noneroded soils across the study area were sampled and analyzed for Cesium-137 to determine a baseline value for noneroded soils (2877 $Bq \cdot m^{-2}$) which was used to predict erosion rates on cultivated soils since the early 1960's. Cultivated hillslopes across the area were also sampled for Cesium-137 redistribution and the Cesium-137 values compared to the noneroded baseline value. Mean hillslope soil erosion rates were estimated as 23 +-8 $tonnes \cdot ha^{-1} \cdot yr^{-1}$ for 0-3% gradient class, 27 +-9 $tonnes \cdot ha^{-1} \cdot yr^{-1}$ for 3-10% gradient class, and 48 +-16 $tonnes \cdot ha^{-1} \cdot yr^{-1}$ for >10% gradient class, representing a soil removal of 3.8 cm, 4.4 cm, and 7.8 cm respectively since 1960. These soil losses represent between 27 and 64% of the topsoil and between 7 and 30% of the solum present within the eroding upslope areas today. These erosion rates occur over approximately 2/3 of the cultivated study area. High rates of soil erosion over such a large portion of the landscape are alarming, considering that the accepted tolerable soil loss is 11.2 to 4.5 $tonnes \cdot ha^{-1} \cdot yr^{-1}$ (Wischmeier and Smith, 1978). Long-term average wind (WEE) and water (USLE) erosion estimates did not equal the Cesium-137 erosion rates.

Introduction

Soil erosion by wind and water is known to reduce a soils fertility and productivity. The severity of wind and water erosion in the Prairie Region of Canada is shown by a few highly local estimates of the actual soil losses or redistribution within the landscape (Toogood 1963; Nicholaichuk and Reed 1978; de Jong et al. 1982, 1983; Martz and de Jong 1985).

During the summer months from 1950 to 1960 Toogood (1963) monitored soil loss from field plots (10% slope, 1.8 m wide by 22.1 m long) in the Black soil zone of Alberta. The maximum soil loss due to rainfall-induced erosion occured on a summerfallow plot and averaged 4.5 $tonnes \cdot ha^{-1} \cdot yr^{-1}$. Nicholaichuk and Reed (1978) estimated maximum soil loss due to snowmelt runoff, from a cultivated watershed near Swift Current, Saskatchewan, as 2 $tonnes \cdot ha^{-1} \cdot yr^{-1}$ over a 6 year period. This estimate was derived from monitoring sediment yield from watersheds.

At present wind erosion soil losses within the Canadian Prairie can only be estimated by use of the Wind Erosion Equation (WEE, Woodruff and Siddoway, 1965). Slevinsky (1983) outlined how the WEE was used to estimate wind erosion losses from fields in Southern Manitoba. Similarly the Universal Soil Loss Equation (USLE, Wischmeier and Smith 1978) can be used to predict rainfall-induced sheet and rill erosion. Voroney et al. (1981) estimated soil loss on a cultivated field in Saskatchewan at 1.7 $tonnes \cdot ha^{-1} \cdot yr^{-1}$. The use of the predictive equations (WEE and USLE) within the prairies has been hampered by a lack of the local data necessary to solve the equations, and the fact that much of the cultivated land within the region has a highly irregular surface form, where both erosion and deposition can occur within a short distance.

Net soil erosion and deposition (soil redistribution) has been estimated from the amount of Cesium-137 present in a soil (de Jong et al. 1982,1983; Martz and de Jong 1985). The long-lived isotope, Cesium-137 (half life 30.2 years), was released into the environment by atmospheric nuclear testing in the 1950's and early 1960's and susequently deposited over the land surface with atmospheric precipitation. Once in contact with soil particles Cesium-137 is strongly absorbed and virtually non-exchangable. Cesium-137 is concentrated in the surface layers of the soil (most commonly, only the surface A-horizon) and is redistributed within the landscape by soil erosion. Areas of the landscape with net soil losses have reduced amounts of Cesium-137 while areas with net soil deposition are enriched with Cesium-137 relative to noneroded, non-depositional areas. The majority of the fallout across the Prairies occurred during the 1960 to 1965 period, peaking in early 1963, thus the estimates of soil redisribution using the isotope are values based on the past 20 to 25 years.

Two localized erosion studies using Cesium-137 as a soil tracer within enclosed basins were conducted in Saskatchewan. De Jong et al. (1983) showed that there was little or no Cesium-137 redistribution within three uncultivated basins, while upper slopes of cultivated basins had soil losses from 20 and 60 kg soil/m^2 . Lower slope deposition gains within these small cultivated basins were between 25 to 80 kg soil/m^2. Martz and de Jong (1985) studied soil erosion patterns in a 180 ha watershed in Central Saskatchewan. They related the total soil and Cesium-137 redistribution to landscape units derived from a digital terrain model of the land surface. Soil losses as high as 57 tonnes$\cdot$ha$^{-1}\cdot$yr^{-1} were observed over 58% of the basin with 90% of the soil gains occurring in less than 3% of the basin.

The soil losses indicated by the Cesium-137 studies indicates high levels of soil erosion occurring within relatively small basins.

This paper presents Cesium-137 erosion estimates for a wide variety of soil landscapes in a 378,000 ha area in West Central Saskatchewan in an attempt to document regional erosion trends.

Methods and Materials

Five Rural Municipalities (Reford #379, Tramping Lake #380, Grass Lake #381, Buffalo # 409 and Round Valley # 410), in West Central Saskatchewan were selected for the study area, as a recent soil survey of the area had just been completed (Figure 1). This study area is mostly situated within the Dark Brown soil zone, but the northerly parts of Rm's 409 and 410 are within the Dark Brown/Black transition zone. The predominant soil parent material within the area is a loamy textured glacial till which is often covered by a thin silty lacustrine veneer. The topography is dominantly gently undulating and hummocky.

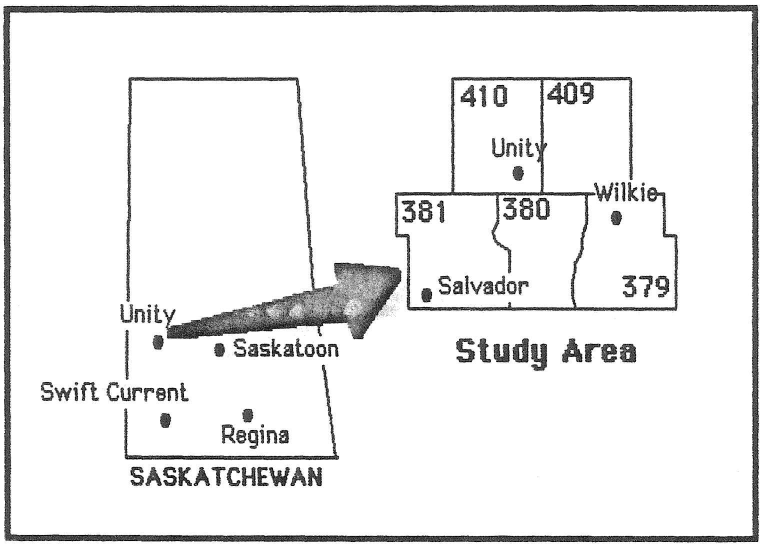

Figure 1. Location of the five Rural Municipal study area within Saskatchewan.

Across the study area 17 non-eroded, native areas were selected to estimate baseline Cesium-137 values (Figure 2). At midslope sites soil samples from the entire A-horizon were collected using a 10.16 cm diameter steel core. Each sample was a composite of four replicates taken at approximately 1 m intervals along the hillslope contour. The baseline samples represented the most common soils occurring within the study area.

Similarly, cultivated hillslopes from the most common soil landscapes were selected and sampled across the study area (Figure 2). The cultivated slopes that were sampled for Cesium-137 redistribution varied from nearly level landscapes (0-3%), to gently and moderately sloping (3-10%) undulating ladscapes with long slope lengths (50-225 m) and hummocky landscapes with short slope lengths (20-50 m), to strongly sloping (>10%) hummocky landscapes with varying slope lengths (10-80 m). The soil parent material of all cultivated hillslopes was composed of a medium textured glacial till and/or glacio-lacustrine material. All of the cultivated hillslope sampling sites had medium textured surface horizons, and in total 43 hillslopes were sampled from 1982 to 1985. Four idealized slope positions were sampled along each hillslope transect, which ran perpendicular to the hillslope contours: crest, upper slope, mid slope and lower slope. At each sampling site, downslope distance and elevation were measured relative to the crest site, and soil observations and samples collected for Cesium-137 analysis. At each slope position four soil cores (10.16 cm diameter) of the entire A-horizon were collected (at 1 m intervals along the contour) and bulked to form one composite.

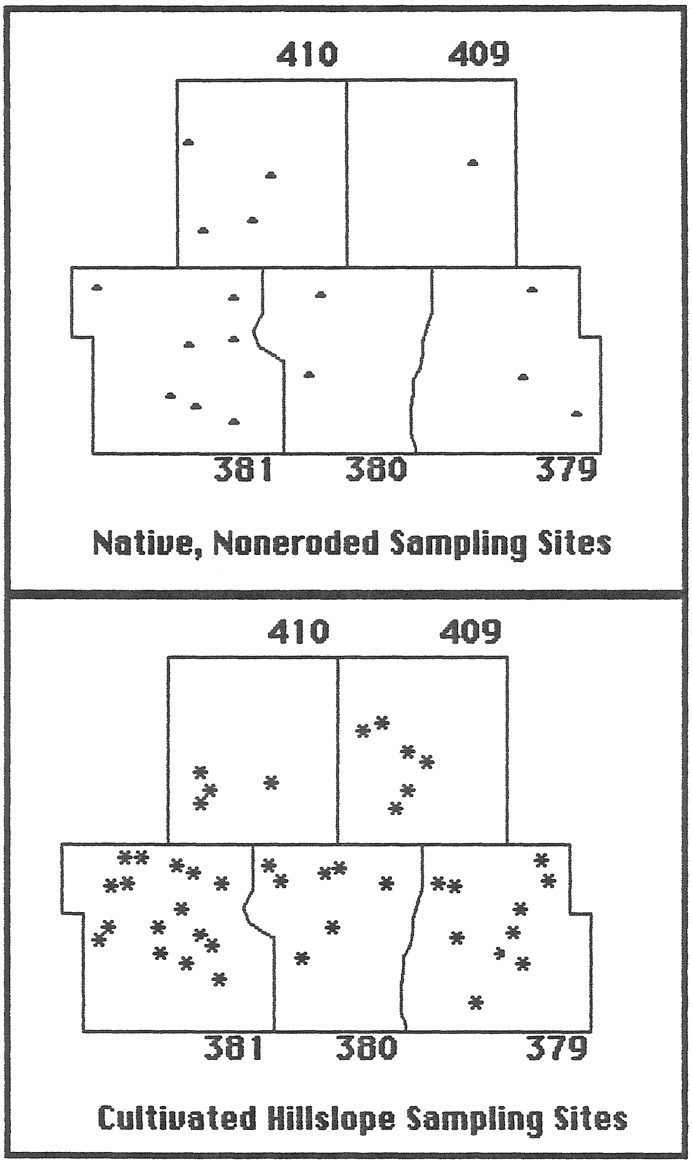

Figure 2. Location of the noneroded, native and cultivated hillslope sampling sites.

All samples were air-dried, weighed and analyzed for Cesium-137 using the methodology outlined by de Jong et al. (1982). Cesium-137 was expressed in Bq/m^2. A Cesium-137 baseline value for non-eroded, cultivated soils was calculated assuming that the Cesium-137 originally deposited on the cultivated sites was the same as the average for the 17 noneroded, native sites, but that 5% could have been lost from upper and middle slope sites due to snow blowing and crop removal (de Jong et al., 1982). The Cesium-137 redisribution on cultivated soils was expressed as :

$$^{137}Cs_R = (^{137}Cs_C - \text{Baseline } ^{137}Cs)/ \text{ Baseline } ^{137}Cs$$

where $^{137}Cs_R$ = the Cesium-137 redistribution at the site (expressed as a loss or enrichment), $^{137}Cs_C$ = the Cesium-137 present at the cultivated sampling site, and Baseline ^{137}Cs = the Cesium-137 baseline value.

A net soil loss or gain was calculated from the percentage Cesium-137 redistribution at each site, assuming a 15 cm thick hectare furrow slice of soil with a bulk density of 1.2 $g \cdot cm^{-3}$ (1800 $tonnes \cdot ha^{-1}$). It was futher assumed that the redisribution had occured over 20 years, thus:

$$\text{Soil Redistribution } (tonnes \cdot ha^{-1} \cdot yr^{-1}) = \frac{(^{137}Cs_R)\ (1800\ tonnes \cdot ha^{-1})}{20\ yrs.}$$

A mean hillslope transect erosion estimate was calculated by averaging those sites within each hillslope transect that showed a net soil loss.

Water erosion on each hillslope transect was also estimated by solving the Universal Soil Loss Equation (USLE) as outlined by Wischmeier and Smith, 1978. The factor values used to solve the equation are outlined in Appendix 1. Similarly wind erosion was estimated on a quarter section basis using the U.S. Soil Conservation Service Wind Erosion Calculator. Factor values used to solve the equation are outlined in Appendix 2.

Results and Discussion

The Cesium-137 values at each of the noneroded native sampling sites (Figure 2) is shown in Table 1. The Cesium-137 concentration on noneroded, native soils was found to be relatively uniform across the study area (C.V. is 5% of the mean), despite differences in soil landscapes and the distance between the sampling sites. This uniformity of noneroded Cesium-137 observations justifies the assumption that the original Cesium-137 distribution was uniform over the whole area and that it can be used to estimate total soil redistribution rates on the cultivated soils.

Table 1. Cesium-137 values at noneroded, native sampling sites.

Soil Subgroup	Texture	Cesium-137 Value (Bq/m^2)
Dark Brown Chernozem	loam	2927
Dark Brown Chernozem	loam	3049
Dark Brown Chernozem	loam	2927
Dark Brown Chernozem	loam	3052
Dark Brown Chernozem	loam	3149
Dark Brown Chernozem	loam	2812
Dark Brown Chernozem	loam	2897
Dark Brown Chernozem	sandy loam	2879
Dark Brown Chernozem	silt loam	3082
Dark Brown Chernozem	clay	3204
Dark Brown Chernozem	clay	2901
Dark Brown Solonetz	loam	2849
Dark Brown Solonetz	loam	3215
Dark Brown Solonetz	clay	3208
Eutric Brunisol	sand	3230
Eutric Brunisol	sand	3160
Melanic Brunisol	loamy sand	2930
MEAN AND STANDARD DEVIATION		3028 +-146
BASELINE CESIUM-137 VALUE (95% OF MEAN)		2877

Using the Cesium-137 baseline value of 2877 Bq·m^{-2} (Table 1), the mean soil erosion rate for the eroding portion of each hillslope was calculated. The 43 hillslopes in this study were grouped into three slope gradient classes to assess the overall mean erosion rates within different landscapes. This grouping clearly indicates that the magnitude of the mean soil erosion rate significantly increased as slope gradient class increased (Figure 3).

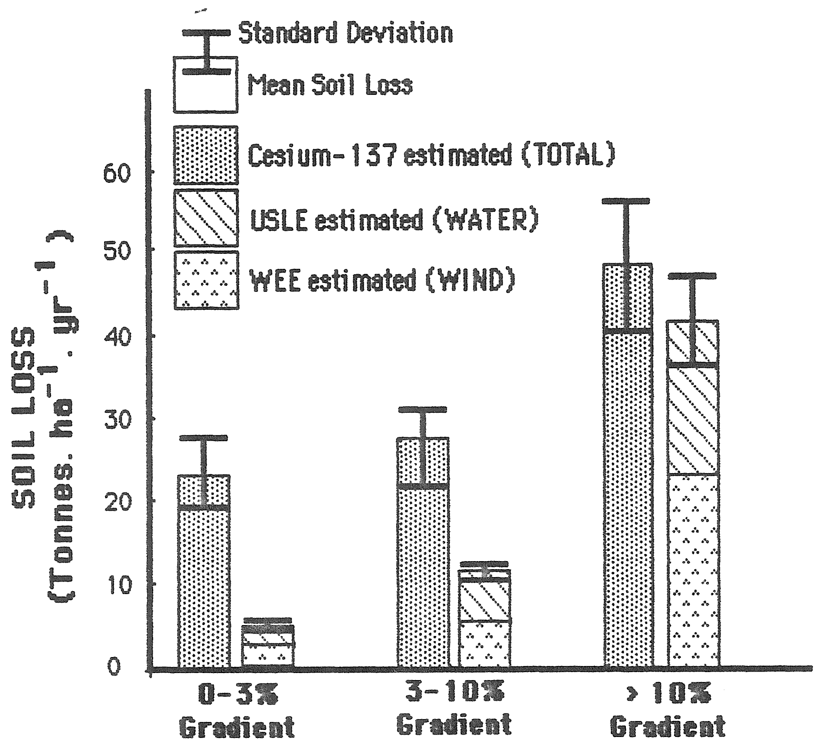

Figure 3. Mean Cesium-137, WEE and USLE estimated hillslope soil losses by slope gradient class.

The mean hillslope transect soil erosion rates (Figure 3) varied from 23 tonnes$\cdot$ha$^{-1}\cdot$yr^{-1} on a 0-3% gradient to 48 tonnes$\cdot$ha$^{-1}\cdot$yr^{-1} on > 10% gradients. Assuming a 15 cm hectare furrow slice of topsoil, the hillslope erosion rates represent soil losses of 1.9, 2.2, and 3.9 mm topsoil$\cdot$yr^{-1} on the 0-3%, 3-10% and > 10% gradient classes, respectively. Over the 20 year time period the total thickness of soil removed is estimated as 3.8 cm (0-3% gradient class), 4.4 cm (3-10% gradient class), and 7.8 cm (>10% gradient class). In many cases these soil losses represent between 27 and 64% of the topsoil and between 7 and 30% of the solum present within the eroding upslope areas today.

The USLE and WEE erosion estimates (Figure 3) did not equal the total erosion rate predicted by Cesium-137. It is important to note that the solutions of the WEE and USLE equations were largely based on the assumed factor values (Appendix 1 & 2). The factor values used in this study were the best available for the study area, but it should be recognized that changing any of the factor values would result in different predicted erosion rates. Greater accuracy in the use of the equations could only be achieved by increasing the amount information on the individual factor values.

The Cesium-137 estimated soil erosion rates are far in excess of the estimated tolerable soil loss (11.2 to 4.5 tonnes$\cdot$ha$^{-1}\cdot$yr^{-1}, or 0.9 to 0.4 mm soil$\cdot$yr^{-1}) according to Wischmeier and Smith (1978). The eroding area within most landscapes, dominantly the upper and middle slope positions, represents approximately 66% of the cultivated area. Therefore, the high net soil losses are occuring on up to 2/3 of the total cultivated acreage and should be cause for alarm within the agricultural community.

Differences in erosion rates for different slope gradient classes (Figure 3) may reflect the nature of the soil erosion processes. In nearly level landscapes overland flow should be minimal and the removal of soil from the 0-3% gradient class (Figure 3) must be largely due to wind erosion. Stronger sloping landscapes would in no way be immune to wind erosion and therefore would also suffer, especially the upper slope areas. Tillage erosion, which is caused by large agricultural implements dragging soil downslope, contributes to the downslope soil movement on hillslopes but, it cannot be expected to move soil great distances. The upper slope portion of the landscape is most affected by tillage erosion, particularily in areas of short, irregular hillslopes which are often cultivated with little or no concern for the land surface contour. Tillage erosion should have the least impact on low slope gradient landscapes.

The crest position of steeper hillslopes may also suffer from increased rates of splash induced soil erosion, as the horizontal splash of soil particles results in a greater net relocation of these particles downslope. Rainfall is often limited within the region and the magnitude of soil movement by splash erosion is not expected to be as significant as the other forms of erosion. Water induced sheet and rill erosion should be expected to increase with increasing slope length and steepness. Therefore, erosion on level landscapes must be mainly due to wind, and to a smaller degree tillage erosion. As hillslope gradient increases the influence of increased overland flow, in combination with wind and increased tillage erosion, contributes to the greatest erosion rates being predicted for, and found on, hillslopes with > 10% gradient (Figure 3). The majority of the eroded soil is most likely deposited in fence rows, depressions, ditches, etc., but some of the wind-blown material will leave the area as atmospheric dust.

Conclusions

Net soil erosion and deposition rates on cultivated hillslopes in West Central Saskatchewan were quantified by assessing the differences between the concentration of Cesium-137 on native, noneroded areas, and the concentrations of Cesium-137 on cultivated hillslopes. This method indicated that the mean rate of soil erosion on the upslope portions of the landscape, which represent up to 2/3 of the cultivated land surface is alarmingly high. Erosion rates varied with slope gradient class: 23 tonnes$\cdot$ha^{-1}yr^{-1} or 1.9 mm topsoil$\cdot$yr^{-1} within the 0-3% gradient class, 27 tonnes$\cdot$ha^{-1}yr^{-1} or 2.2 mm topsoil$\cdot$yr^{-1} within the 3-10% gradient class, and 48 tonnes$\cdot$ha^{-1}yr^{-1} or 3.9 mm topsoil$\cdot$yr^{-1} within the > 10% gradient class. These soil losses represent between 27 and 64% of the topsoil and between 7 and 30% of the solum present within the eroding upslope areas today. The dominance of wind erosion within the area was most evident in the level landscapes (0-3% gradient class), where the observed rates of erosion could only be explained by wind, and to a lesser degree tillage erosion. These high rates of soil erosion present a serious soil quality problem.

WEE and USLE erosion estimates for transects did not equal the Cesium-137 erosion rates, and were highly dependant on the assumed factor values. Greater accuracy in the use of the equations could only be achieved by increasing the amount information on the individual factor values.

APPENDIX 1: USLE Erosion Estimation.

A=R X K X LS X C X P

The USLE water erosion estimates were calculated using the method outlined by Wischmeier and Smith (1978). The factor values used represent some actual measured values for hillslope transects and some estimated long-term averages for the study area.

R= 20 Imperial Units (Stolte and Wigham, 1985)

R_S= 3 Imperial Units (15% of annual R; Wall et al., 1983)

K= Calculated for the soil type within each transect (using the Soil Erodibility Nomograph(Wischmeier and Smith, 1978). Values range from 0.25 for a Clay Loam to 0.32 for a Silt Loam textured soil.

LS= Slope gradient and length was calculated for each transect using the Slope Effect Nomograph(Wischmeier and Smith, 1978). Values range from 0.13 (0.7% gradient & 148 ft length) to 7.0 (24% gradient & 200 ft length).

C= 0.44 Imperial Units for a Spring Wheat-Spring Wheat-Summerfallow Rotation.

P= 1 Imperial Unit for no conservation practices.

APPENDIX 2: WEE Erosion Estimation.

E= f (I, K, C, L, V)

The WEE wind erosion estimates were calculated with a U.S. Soil Conservation Service Wind Erosion Calculator. The factor values used represent estimated long-term averages for quarter section fields (within the three topographic classes) the study area.

I= Wind Erosion Group (WEG) 4L (medium textured soils) with an "I" Correction Factor of 1.9 for 3-10% gradient class and 3.6 for >10% gradient class.

K= 0.75 Soil Ridge Roughness Factor.

C= 30 Imperial Units (Annual Climatic Value from PFRA, 1985)

L= 3000 ft fetch.

V= 1250 $lbs \cdot acre^{-1}$ residue.

METRIC CONVERSION FACTORS

1) Tons·acre^{-1}·yr^{-1} x 2.24 = Tonnes·ha^{-1}·yr^{-1}

2) lbs· acre^{-1} x 1.121 = kg·ha^{-1}

3) ft x 0.305 = m

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