ACTA GEOLOGICA HISPANICA, v. 35 (2000), nº 3-4,p. 219-228

Surface erosion assessment using ^{137}Cs: examples from New Zealand

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ABSTRACT

The ^{137}Cs technique has provided the first quantitative, medium-term data on rates of soil redistribution by surface erosion on both cropland and rangeland in New Zealand. Use of the technique has demonstrated: high rates of soil redistribution by water erosion at two cropland sites under intensive vegetable production; a slow rate of net loss of soil by wind erosion associated with arable farming; a strong association between vegetation depletion and wind erosion on grazed rangeland.

Research has also provided data on natural short-range variability of ^{137}Cs in uneroded soils, and a technique for independently estimating ^{137}Cs reference values from rainfall. The greatest research need remains the development of robust, accurate calibration procedures for converting ^{137}Cs measurements to rates of erosion.

Key words: Caesium 137. Erosion rates. Soil redistribution. Water erosion. Wind erosion. Cropland. Rangeland. Reference value.

INTRODUCTION

Surface erosion by wind and water has been widely reported on cropland and rangeland in New Zealand (e.g., Eyles, 1983), yet little quantitative information is available on surface erosion rates. As a result, indirect assessment of surface erosion using the radionuclide tracer caesium-137 (^{137}Cs) has been used to estimate medium-term surface erosion rates at a number of sites throughout New Zealand.

The major advantages of the ^{137}Cs technique are: rates of erosion are medium-term estimates (net erosion since the first appearance of ^{137}Cs in the environment); it can be used on both cultivated and uncultivated soils; only a single set of measurements need be made; both erosion and deposition can be measured so the net effect of erosion and/or tillage can be assessed; it has the potential to be used as an environmental indicator to monitor rates of surface erosion in the future. However, the technique requires a number of assumptions about the environmental behaviour of ^{137}Cs, and the relationship between ^{137}Cs loss and soil loss. These are reviewed in detail by Loughran et al. (1990), Ritchie and McHenry (1990), Walling and Quine (1990, 1993) and Basher et al. (1995).

Use of ^{137}Cs has contributed significantly to understanding rates of surface erosion in New Zealand. Emphasis has been on application of the technique to provide field-based data on erosion rates, with limited research to

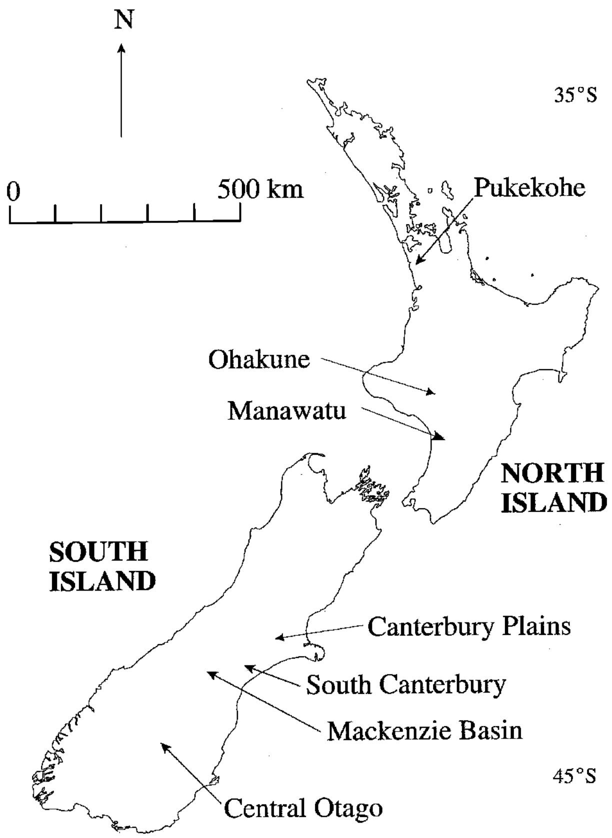

Figure 1. Location of study sites.

further develop the technique. This paper summarises recent research applying the technique to assessment of water and wind erosion rates on cropland and rangeland, and on development of techniques for estimating reference values and natural spatial variability of ^{137}Cs.

APPLICATIONS OF ^{137}CS TO SURFACE EROSION ASSESSMENT

Rates of surface erosion by wind and water on cropland and rangeland have been estimated from variation in ^{137}Cs areal activity relative to the reference value. Measurement of ^{137}Cs areal activity has been based on samples taken with small diameter cores (28 or 39 cm^2 area), with some taken from a larger area (1300 cm^2) using a scraper frame to provide information on the vertical distribution of ^{137}Cs. Each sample of <2 mm air-dried soil was analysed for ^{137}Cs activity at the National Radiation Laboratory, Christchurch by high resolution gamma spectroscopy using HpGe detectors, as described by Basher et al. (1995). The precision of ^{137}Cs activity measurement was ±5-10%. Erosion rates have generally been calculated by the linear proportional model for cultivated soils and the profile distribution model for uncultivated soils (see Walling and Quine, 1990, 1993; Basher et al., 1995; Basher and Webb, 1997), except where otherwise indicated. Locations referred to in the text are shown in Fig. 1.

Cropland

Severe localised sheet and rill erosion occurs infrequently in the loess-mantled South Canterbury downlands, but there is no data on longer term erosion rates. Basher et al. (1995) examined patterns of ^{137}Cs distribution at two sites with contrasting long-term land uses (cropping and pasture). The soil sampling pattern was based on a series of transects covering all slope elements. The reference value for this area was estimated at 474±71 Bq/m^2.

Table 1. Relationship between slope element, ^{137}Cs areal activity and mean erosion rates on cropland in the South Canterbury downlands (reference value = 474 Bq/m^2). Note: N = number of samples; s.e. = standard error of the mean; positive erosion rates indicate deposition.

Slope element	N	^{137}Cs areal activity (Bq/m^2)		Mean erosion rate	Topsoil depth (cm)
		Mean±s.e.	Range	(t/ha/yr)	Mean±s.e.
interfluve	14	471±38	138-658	0	19.0±0.9
shoulder	18	380±24	232-533	-13	15.3±1.1
backslope	23	428±22	259-675	-6	19.6±1.2
footslope	8	523±35	469-760	5	29.1±6.0
toeslope	5	510±15	458-550	7	24.8±1.0
swale	11	600±4.9	342-827	16	42.9±7.1
Mean	79	463±15	138-827	0	23.2±1.6

Table 2. ^{137}Cs and wind erosion rate data for Canterbury (C1, C2) and Manawatu (M1, M2, M3) sites. * the residual is the difference between measured ^{137}Cs areal activity and the reference value.

	Reference		^{137}Cs areal activity			
	N	value (Bq/m²)	Mean±s.e. (Bq/m²)	Range (Bq/m²)	Mean residual* (%)	Mean erosion rate t/ha/yr
C1	48	599	422±10	282-535	-30	-16
C2	40	599	424±8	345-591	-29	-17
M1	52	712	622±28	285-1094	-13	-14
M2	42	653	589±16	342-793	-10	-11
M3	14	660	572±31	398-836	-13	-12

At the cropping site, ^{137}Cs areal activity ranged from 138-827 Bq/m^2, with a mean of 463±15 Bq/m^2. This contrasted with the pasture site where ^{137}Cs areal activity ranged from 356-937 Bq/m^2, with a mean of 550±27 Bq/m^2. The results suggested soil redistribution by wind and water at the cropping site, estimated to range from a loss of 46 t/ha/yr to deposition of 49 t/ha/yr, but little net soil loss. There were clear relationships between slope position, ^{137}Cs areal activity and topsoil depth (Table 1), consistent with redistribution of soil from shoulder slopes to footslopes and swales. The contribution of tillage erosion to these patterns of ^{137}Cs distribution was not evaluated but is likely to be substantial in a landscape comprised of convexo-concave slopes, and where the highest erosion rates occurred on convex upper slopes (c.f. Govers et al., 1996). The results also suggested significant soil redistribution by wind erosion on the interfluves, although the landform-based sampling pattern was considered inadequate to characterise spatial patterns of soil redistribution on interfluves.

The Canterbury and Manawatu plains are major cropping areas with a windy climate. Severe erosion during infrequent wind storms has been observed on the Canterbury plains (e.g., Hunter and Lynn, 1988), but not on the Manawatu plains. Basher et al. (submitted) estimated medium-term rates of wind erosion at 2 sites in Canterbury and 3 in the Manawatu. Soil samples were collected from each site in a grid pattern with a 40-50 m grid spacing. Variation in ^{137}Cs areal activity was converted to rates of erosion using the mass balance model of Walling and He (1997).

Mean ^{137}Cs areal activity was significantly lower than the reference value at all sites (Table 2). Canterbury sites had very similar values for the mean (422 and 424 Bq/m^2) and range of ^{137}Cs areal activity, with no sampling sites having ^{137}Cs areal activity greater than the reference value. Mean ^{137}Cs residual at both sites was c.-30%. At Manawatu sites mean ^{137}Cs areal activity was higher (572-622 Bq/m^2) and mean ^{137}Cs residuals lower (-10% to -13%), due to higher rainfall and lower mean erosion rates. Mean erosion rates for Canterbury were c.16 t/ha/yr, compared with 11-14 t/ha/yr for the Manawatu. The grid sampling strategy used was inadequate to characterise spatial patterns of soil redistribution within the fields by wind erosion, but did provide a robust estimate of the mean ^{137}Cs areal activity and erosion rate for each field. The results suggested similar erosion rates in both areas, and that erosion processes were dominated by slow, cumulative soil loss rather than infrequent, large events.

Long-term, intensive commercial vegetable production at Pukekohe under a subtropical climate with high-intensity, short-duration rain storms can cause severe water erosion. Sediment yields measured at plot (57 t/ha/yr) and catchment scales (0.5 t/ha/yr) in this area by Basher et al. (1997) suggested large quantities of soil are mobilised within fields by storms, but little sediment reaches the drainage system. Patterns of ^{137}Cs distribution in three fields were used to examine the within-field soil redistribution (Basher, in prep). Soil samples were collected from three fields, using a grid pattern with a 15-20 m grid spacing. Variation in ^{137}Cs areal activity was converted to rates of erosion using the mass balance model of Walling and He (1997), incorporating analysis of tillage erosion.

^{137}Cs areal activity ranged from 126 to 2304 Bq/m^2 with a mean of 644±21 Bq/m^2, compared to a reference value of 774 Bq/m^2. All three fields had mean ^{137}Cs areal activity lower than the reference value, with a large range of values in each field (Table 3). Each field showed a similar pattern of down-field increase in ^{137}Cs areal activity, indicating loss of ^{137}Cs over most of the field, with small areas at the base of the field with lower slope gra-

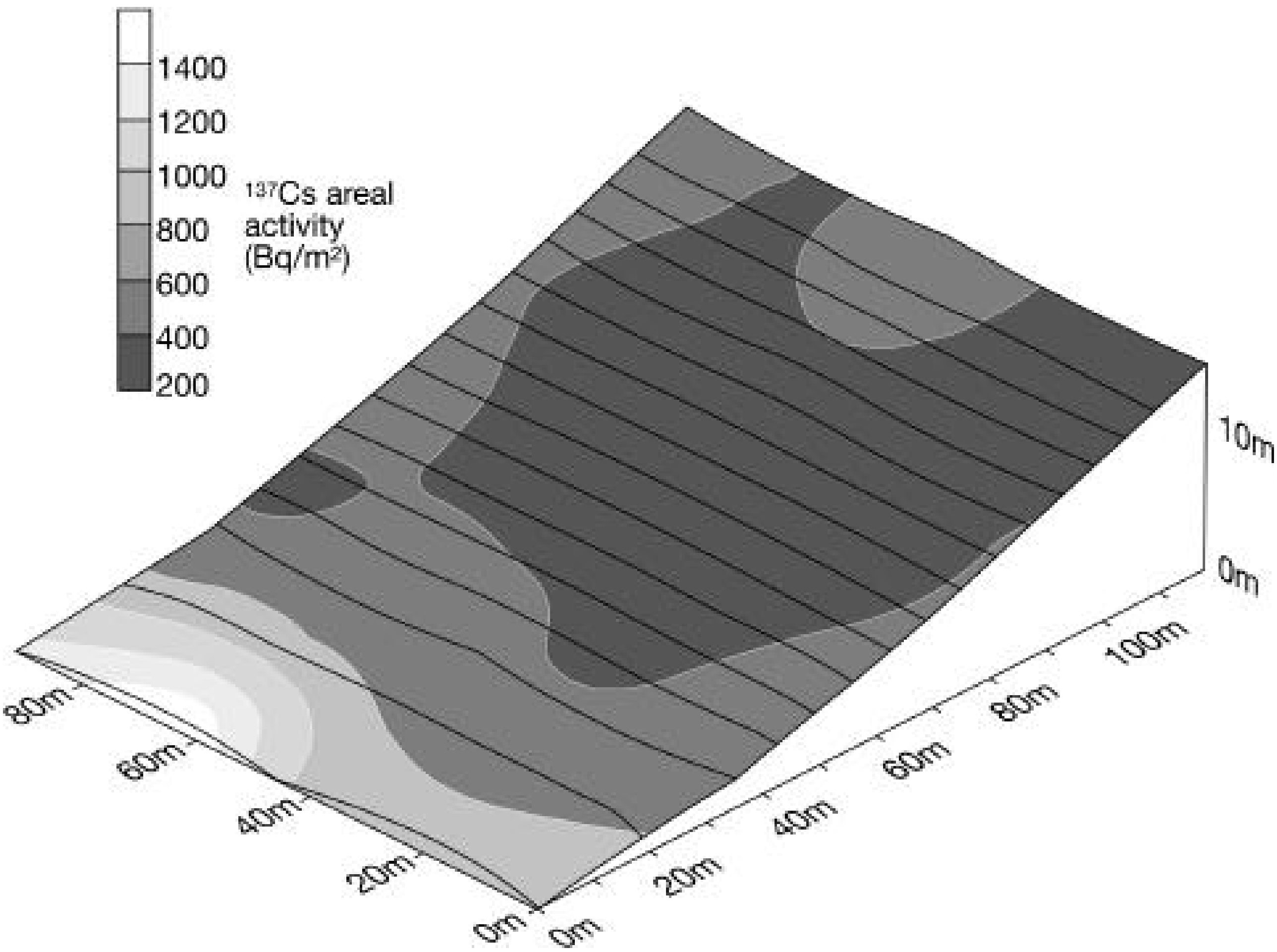

Figure 2. Distribution of ^{137}Cs within one field at Pukekohe.

dient having ^{137}Cs areal activity greater than the reference value (Fig. 2). The data suggested erosion rates up to 98 t/ha/yr and deposition rates up to 109 t/ha/yr. Large areas on the upper slopes within fields had lost more than 30 cm of soil, and smaller areas on the lower slopes gained over 40 cm, resulting in a net loss from the three fields of c.10 cm of soil. Analysis suggested a small proportion of the net erosion and deposition was due to tillage erosion since the topography of the fields showed little profile or contour curvature. The ^{137}Cs data characterise within-paddock soil redistribution, and aid understanding of sediment dynamics in this landscape by providing a link between plot-scale and catchment-scale measurements.

Long-term continuous carrot growing on erodible, volcanic ash-derived soils in the Ohakune area can cause severe soil loss. Erosion rates have been estimated at a site used continuously for carrot production for the last 16 years (Basher, in prep). Soils were sampled on a 15 m grid pattern covering all slope elements in a gently undulating landscape. Variation in ^{137}Cs areal activity was converted to rates of erosion using the mass balance model of Walling and He (1997).

^{137}Cs areal activity was highly variable (89 to 2034 Bq/m^2) with the majority of samples having ^{137}Cs areal activity below the reference value (955 Bq/m^2). Patterns of ^{137}Cs areal activity were closely related to slope position and slope angle (Table 4), with mean ^{137}Cs areal activity highest on toeslopes (1017 Bq/m^2) and lowest on backslopes (255 Bq/m^2). All slope positions, except toeslopes, showed a net loss of ^{137}Cs, which ranged from -52 to -73%. Mean ^{137}Cs areal activity for all samples was 475 Bq/m^2, equivalent to a 50% loss of ^{137}Cs. Mean erosion rates were extremely high for all slope positions (80-

Table 3. Values of ^{137}Cs areal activity in 3 fields at Pukekohe (reference value = 774 Bq/m^2).

		^{137}Cs areal activity (Bq/m^2)		^{137}Cs residual (%)		Erosion rate (t/ha/yr)	
Field	N	Mean±s.e.	Range	Mean	Range	Mean	Range
P1	62	527±35	247-1949	-33	-67 to 92	-31	-72 to +60
P2	98	702±48	126-2304	-11	-78 to 177	-8	-98 to + 109
P3	112	658±18	358-1559	-13	-45 to 90	-7	-35 to +34

142 t/ha/yr), except for toeslopes which have a net deposition rate of 22 t/ha/yr. Mean erosion rate for all samples was almost 90 t/ha/yr, equivalent to a soil loss rate of 13 mm/yr. These rates are extremely high and suggest that total soil loss in eroding sites has been up to 50 cm, and in accumulating sites more than 50 cm of soil has been deposited. Mean soil loss ranges from 32 cm on backslopes to mean deposition of 5 cm on toeslopes. These estimated losses are consistent with independent estimates of soil deposition from the vertical distribution of ^{137}Cs, and with surface elevation differences between the cropped field and an adjacent pasture field (Fig. 3). The spatial patterns and magnitude of redistribution of ^{137}Cs at Ohakune are very similar to those at Pukekohe.

Rangeland

Semi-arid grazing land in central Otago has a long history of severe vegetation depletion as a result of grazing by sheep and rabbits, and frequent use of fire to manage the grasslands. However, little is known of the extent of erosion associated with vegetation depletion. Hewitt (1996) described the patterns of ^{137}Cs distribution on hillslopes oriented across the prevailing wind. There were clear relationships between topography, ^{137}Cs distribution and topsoil depth (Table 5), with far lower mean ^{137}Cs values on windward slopes (136-206 Bq/m^2 for upper slopes) than leeward slopes (305-317 Bq/m^2), suggesting wind erosion was redistributing soil in this landscape. Hewitt (1996) estimated about 3.5 cm of topsoil had been lost from sunny backslopes, while footslopes and leeward slopes had gained smaller amounts (0.3-0.6 cm) of soil.

Grazing land in the Mackenzie Basin has severely depleted vegetation, with extensive visual evidence of wind erosion of loessial soils on terraces. Basher and Webb (1997) compared patterns of ^{137}Cs distribution with vegetation cover and microtopography along six transects. Mean ^{137}Cs areal activity was 351±9 Bq/m^2, compared with a reference value of 422±63 Bq/m^2, and indicated a mean soil loss of 2.2 cm. Few sampling sites had ^{137}Cs areal activity greater than the reference value and most of these sites were on tussock pedestals or well vegetated areas. Contrasts in ^{137}Cs areal activity between bare sites (268±17 Bq/m2) and vegetated sites (418±15 Bq/m^2) suggested a soil loss of 3.9 cm from bare ground. On tussock pedestals the mean ^{137}Cs areal activity was slightly greater (457±25 Bq/m^2) than the reference value, while deflated sites had a mean of 326±9 Bq/m^2 (an average loss of 2.8 cm of soil). The results suggested that vegetated areas, including pedestals, were stable or gaining soil, while bare deflated sites were losing soil. Topsoil depths

Table 4. Relationship between slope element, ^{137}Cs areal activity and mean erosion rates, Ohakune (reference value = 955 Bq/m^2).

Slope element	N	^{137}Cs areal activity (Bq/m^2)		Mean erosion rate	Topsoil depth (cm)
		Mean±s.e.	Range	(t/ha/yr)	Mean±s.e.
crest	7	375±50	190-558	-102	24.4±0.7
shoulder	14	338±21	232-505	-109	26.9±0.9
backslope	34	255±16	89-539	-142	25.8±0.5
footslope	12	460±43	194-807	-80	31.3±1.9
toeslope	19	1017±98	529-2034	22	58.3±5.2
Mean	86	475±40	89-2034	-89	33.8±1.9

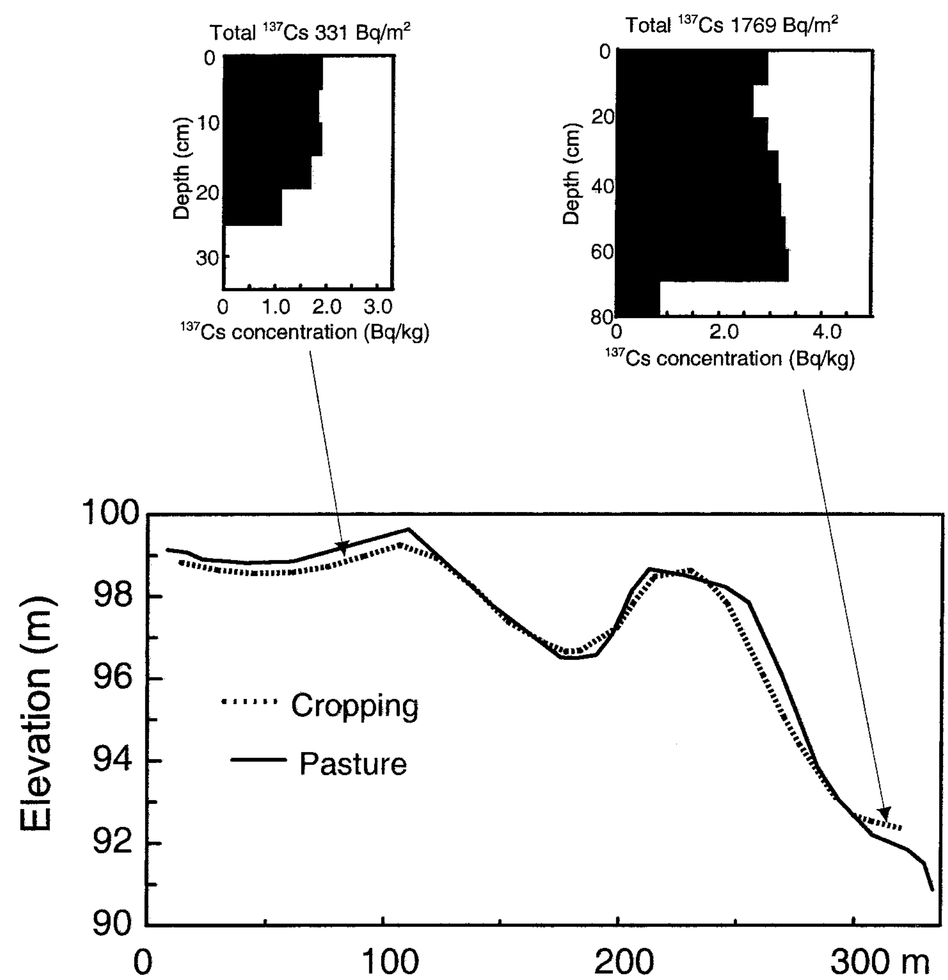

Figure 3. Relationship between differences in elevation between cropped field and an adjacent pasture field, and ^{137}Cs vertical distribution in soils. Note that where elevation differences suggest erosion of up to 50 cm of soil ^{137}Cs areal activity is low and there is no ^{137}Cs below 25 cm. Where elevation differences suggest deposition of more than 50 cm of soil ^{137}Cs areal activity is very high and ^{137}Cs is found down to at least 80 cm.

showed similar trends to ^{137}Cs areal activity and supported the erosion rates estimated using ^{137}Cs.

DEVELOPMENT OF THE ^{137}CS TECHNIQUE

Estimation of the reference value

Accurate estimation of the reference value is essential for calculating losses and gains of ^{137}Cs to determine erosion and deposition rates. The reference value is normally estimated from local 'undisturbed' sites. However, often little is known of the site history and site stability is inferred from the vertical distribution of ^{137}Cs. In the South Canterbury downlands, differences between ^{137}Cs measured at 'undisturbed' local sites and a prediction of the reference value from measurements of atmospheric fallout (Matthews, 1989; Basher et al., 1995), led to development of alte

rnative approaches for estimating the reference value.

Within a given latitudinal range, atmospheric fallout of ^{137}Cs is a linear function of rainfall (e.g., Low and Edvarson, 1960; Davis, 1963; Lance et al., 1986; Arnalds et al., 1989). Matthews (1989) used records of fallout deposition of ^{90}Sr and ^{137}Cs to derive a model, applicable to New Zealand, to predict reference values from rainfall:

$$fallout\text{-}Cs = 53.4 + 0.67R$$

where R=mean annual rainfall (mm) and *fallout-Cs* = cumulative ^{137}Cs deposition (Bq/m^2) to the end of 1990. Since there has been no fallout since 1990, cumulative deposition for subsequent years can be calculated by this equation and correcting the result for radioactive decay.

The performance of this model was tested in two areas (South Canterbury and Manawatu) by Basher and Matthews (1993) using soils taken from meteorological enclosures (with known site history and rainfall), cemeteries and permanent pasture sites. For this limited data set there was a 1:1 relationship between mean measured ^{137}Cs in soils and that predicted from atmospheric fallout ^{137}Cs. Because of natural variability in ^{137}Cs areal activity, individual measurements of ^{137}Cs were poorly correlated with atmospheric fallout ^{137}Cs.

Subsequent testing of the model over a wide range of latitude and rainfall has confirmed its general applicability (Basher and Matthews, in prep.). Results from 22 sites with known history covering a rainfall range from c.350-c.2800 mm annual rainfall (Table 6 and Fig.4) confirm there is a strong linear relationship between ^{137}Cs areal activity measured in undisturbed soils and rainfall (r^2 = 0.85):

$$soil\text{-}Cs = 149.5 + 0.51R$$

While there is a strong relationship between soil-Cs and predicted fallout-Cs for these sites (r^2 = 0.85), the values measured in soil tend to be lower than the predicted fallout-Cs (Fig. 4). Despite the slight difference between fallout-Cs and soil-Cs models use of either equation provides a tool for independently estimating reference values and verifying local measurements of the reference value.

Natural variability of ^{137}Cs

Adequate characterisation of natural variability of ^{137}Cs is essential to determine whether locally measured reference values are based on adequate sample numbers, and to interpret erosion rate data derived from ^{137}Cs measurements. In early studies using ^{137}Cs, inadequate attention was paid to natural variability, and understanding of the causes of natural variability remains poor (Sutherland, 1991, 1996).

Measurements of ^{137}Cs variability at sites throughout New Zealand (Table 6) generally have coefficients of variation (CV) in the range 10-20% with a median of 17%, similar to those reported elsewhere in the world (Sutherland, 1991, 1996). However, the mean CV across all sites was 21% because three sites had very high CVs. At most sites 10-15 samples were required to estimate the mean ^{137}Cs areal activity to ±10% at 90% confidence interval. The natural variability of ^{137}Cs requires further study to determine its causes, to provide protocols for determining the numbers of samples to be collected at reference sites, and to assist in further developing calibration procedures. Erosion rates can only be calculated where measured ^{137}Cs areal activity lies outside the standard error of the reference value estimate.

Calibration procedures

The greatest research need in New Zealand remains the development of robust, accurate calibration procedures for converting ^{137}Cs measurements to rates of erosion. Erosion rate calculations have mostly utilised the linear proportional model for cultivated soils and a modified profile distribution model for uncultivated soils (see Walling and Quine, 1990, 1993; Basher et al., 1995; Basher and Webb, 1997). These are simple methods that ignore

Table 5. Relationship between slope element and ^{137}Cs areal activity, central Otago (reference value = 275±9 Bq/m^2).

	Slope element	N	^{137}Cs areal activity		Topsoil depth
		(Bq/m^2)	(cm)		
			Mean±s.e.	Range	Mean±s.e.
Windward	crest	12	206±17	114-288	3.9±0.4
	backslope	9	136±23	61-251	4.7±0.4
	footslope	14	298±17	200-395	10.8±1.3
Leeward	backslope	11	314±26	151-446	13.2±0.6
	footslope, linear	13	305±26	45-394	11.3±1.1
	footslope, convex	11	317±30	197-557	12.9±0.8

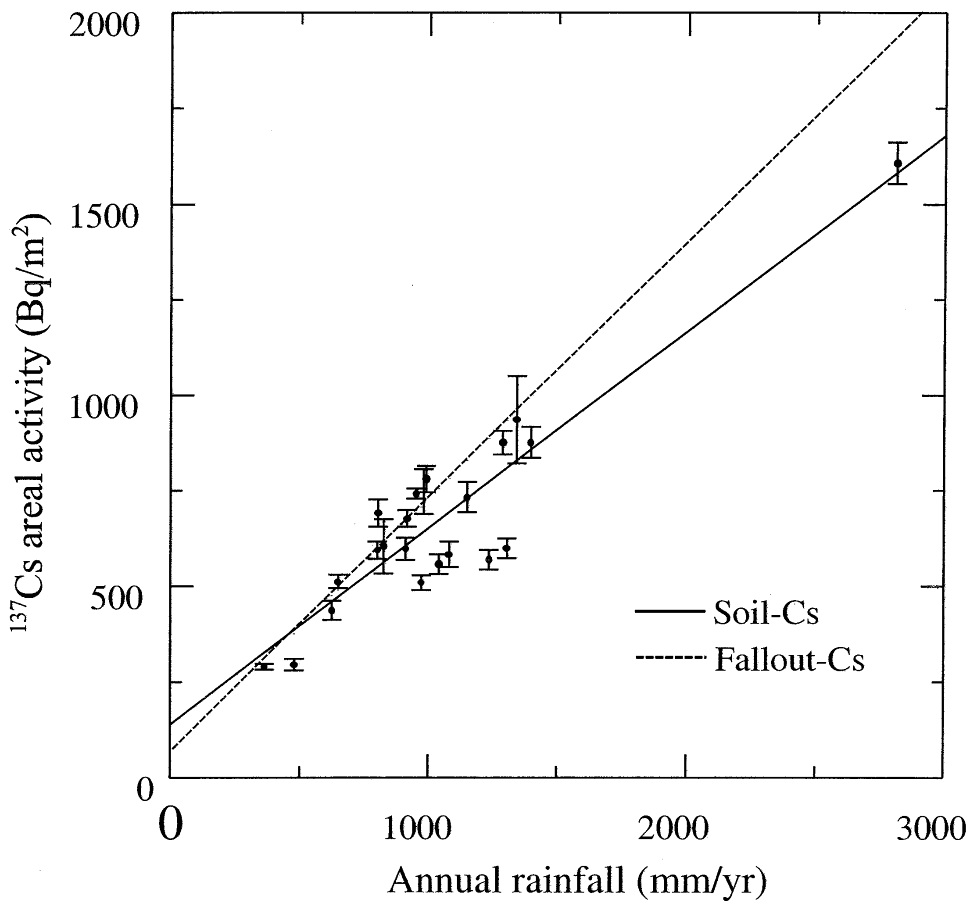

Figure 4. Relationship of soil ^{137}Cs areal activity to mean annual rainfall at undisturbed sites. Regression lines.

the time varying accumulation of atmospheric fallout of ^{137}Cs, the post-depositional vertical movement of ^{137}Cs within soils, the erosion of some ^{137}Cs before its incorporation by cultivation, and the incorporation of subsoil containing no ^{137}Cs. However, the only data that are required to utilise these models are the depth of the cultivation layer, bulk density of the soil, % reduction in ^{137}Cs areal activity (residual) at each sampling point, distribution of ^{137}Cs with depth in the soil, and the ^{137}Cs reference value.

Erosion rates for cultivated soils are calculated as:

$$E = \frac{BdX}{T} * 10^4$$

where E = mean annual soil loss (t/ha/yr); B = bulk density of the soil (t/m^3); d = depth of cultivation layer (m); X = percentage reduction in ^{137}Cs areal activity; T = time since beginning of fallout deposition or cultivation (yr). Erosion rate calculations for uncultivated soils use the exponential decline of ^{137}Cs with soil depth (modified from Zhang et al. 1990):

$$Ah = Aref\ (1 - e^{-h(a+bh)})$$

where A_h = amount of ^{137}Cs above depth h in the soil (Bq/m^2); A_{ref} = ^{137}Cs reference value (Bq/m^2); a, b = coefficients describing the exponential decline of ^{137}Cs with soil depth. Measured data on the depth distribution of ^{137}Cs are modeled to calculate a and b, and these values are used to calculate depth of soil (h, cm) lost from the measured loss of ^{137}Cs (Z):

$$h = \frac{-a + \sqrt{a^2 - 4b\ln\left(1 - \frac{Z}{100}\right)}}{2b}$$

Mass balance models that take account of the inputs and losses of ^{137}Cs from the soil profile over the period of ^{137}Cs fallout have recently been used to simulate ^{137}Cs loss and gain with soil erosion and deposition (using the mo-

Table 6. Mean and range of ^{137}Cs areal activity recorded in soils at undisturbed sites in New Zealand (corrected to 1990); N´ = number of samples required to estimate mean ^{137}Cs areal activity to ±10% at 90% confidence interval.

Rainfall	N	N'	^{137}Cs areal activity (Bq/m^2)		CV
(mm/yr)			Mean±s.e	Range	
364	10	3	288±8	230-339	10
478	10	12	293±15	187-389	19
625	11	15	436±25	328-639	22
648	4	9	511±18	443-597	13
800	11	7	594±22	447-748	14
802	14	12	691±36	513-863	20
825	11	65	604±72	309-1091	45
910	10	11	598±29	486-823	18
915	10	5	677±21	576-789	12
950	4	3	742±14	666-778	7
971	10	7	509±19	319-581	14
980	8	31	748±59	337-1075	30
991	4	14	780±34	651-950	16
1040	10	10	558±26	450-785	17
1079	12	14	583±33	405-830	21
1150	10	14	732±39	445-909	20
1236	11	9	569±26	438-685	17
1289	8	6	876±31	668-1028	13
1305	10	9	600±26	424-747	16
1343	6	84	935±114	602-1753	46
1398	11	10	876±41	698-1199	17
2809	10	5	1608±54	1339-1954	13

dels and software described in Walling and He, 1997). These models require data on more parameters describing the behavior of ^{137}Cs. For cultivated soils, values of 3 parameters are required: the proportion of the annual ^{137}Cs fallout susceptible to removal by erosion before incorporation by tillage (γ); the relaxation mass depth for the initial distribution of fallout ^{137}Cs (H, kg/m^2); a particle size correction factor (P), to account for selective removal of clay particles enriched in ^{137}Cs. The diffusion and migration model for uncultivated soils requires values for 4 parameters: H and P, the migration rate (V, $g/cm^2/yr$) and diffusion coefficient (D, $g^2/cm^4/yr$). Values of D and V can be calculated from the measured vertical distribution of ^{137}Cs.

Erosion rate calculations are sensitive to the choice of input parameters. Table 7 shows the range of values for mean erosion rate at Pukekohe estimated using the mass balance model range from 2.5 to 31.8 t/ha/yr, depending on the choice of values for H and g. This compares with a value of 21 t/ha/yr derived from the linear proportional model. Similarly, on uncultivated soils erosion rate estimates are sensitive to the value of H. For the Mackenzie data erosion rate estimates range from 1.6 to 2.4 t/ha/yr depending on the value of H, and are significantly lower than erosion rates calculated using the profile distribution model (6.8 t/ha/yr). For routine use of mass balance models in New Zealand, data will have to be collected on P and H, and a procedure developed for estimating values of g, to provide improved erosion rate estimates from ^{137}Cs data.

Table 7. Effect of varying γ and H on mean and range of erosion rate estimates at Pukekohe using mass balance 2 model (Walling & He, 1997).

	Erosion rate (t/ha/yr); mean ±s.e		
	γ=0	γ=0.5	γ=1.0
H=1	-31.8±9.5	-8.2±3.2	-2.5±0.8
H=2	-31.8±9.5	-11.2±3.9	-4.7±1.4
H=4	-31.8±9.5	-15.2±4.9	-8.1±2.5
H=8	-31.8±9.5	-19.7±6.1	-12.9±4.0

CONCLUSIONS

Use of the ^{137}Cs technique has made a significant contribution to quantitatively understanding the significance of surface erosion in New Zealand. Research has shown that rates of soil redistribution by surface erosion processes are very high in areas used for intensive vegetable production. Wind erosion is leading to a net loss of soil on arable cropland and grazed rangeland with depleted vegetation cover.

The greatest research need remains the development of robust, accurate calibration procedures for converting ^{137}Cs measurements to rates of erosion. Reference values for ^{137}Cs can be estimated from rainfall, providing an independent check on the accuracy of values measured at local sites.

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