Rates of soil erosion in Australia determined by the caesium-137 technique: a national reconnaissance survey

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Abstract A national reconnaissance survey of soil erosion using ^{137}Cs is being conducted throughout Australia, and results from South Australia, Victoria, New South Wales and Queensland are presented. Surveyed transects were sampled by coring for ^{137}Cs on grazing, rotational cropping, vineyard and woodland sites. The highest net soil losses are of the order 8 to 15 t ha^{-1} year^{-1} under conditions of cropping (wheat rotation, potatoes, vegetables and vines). Land use appears to be the main control on soil erosion, despite large variations in rainfall between sites.

INTRODUCTION

Rates of soil erosion at the regional scale may be estimated from drainage basin sediment yields, but if sediment delivery ratios are unknown, soil loss rates from slopes will be difficult to determine. The caesium-137 (^{137}Cs) technique (Ritchie & McHenry, 1990), on the other hand, has the potential to provide information on slope net soil loss across the landscape. If sites for sampling are selected, for example, on a land system basis, it may be possible to achieve a broad-scale perspective on soil erosion. In 1990, the Australian Department of Primary Industries and Energy, through its National Soil Conservation Program (now the National Landcare Program), provided funds for a national reconnaissance survey of soil erosion using the ^{137}Cs method. The aim of the survey is to provide data on net soil loss due to sheet erosion on a transect basis for agricultural and pastoral districts selected by soil conservation officers of the states and territories of Australia. The project is being coordinated by the authors, but each state/territory has its own coordinator responsible for site selection, sample collection and sample dispatch to gamma detectors at the Australian Nuclear Science and Technology Organization at Lucas Heights, near Sydney, and the Department of Geography at The University of Newcastle. In addition, postgraduate scholarships were provided for three students to carry out parts of the survey. The results reported in this paper are for all sampled districts in South Australia, Victoria and Queensland, with results for New South Wales being confined to four districts studied in greater detail by the students Saynor (1994), Surjan (1994) and Curtis (1995).

METHODS

The ^{137}Cs technique for measuring net soil loss is well documented (e.g. Walling & Quine, 1991; Loughran, 1994). There is, however, a choice of models to convert ^{137}Cs measurements into estimates of net soil loss (Walling & Quine, 1990). The approach adopted in this survey has been developed in Australia (Elliott *et al.*, 1990), where the percentage loss of ^{137}Cs at a sampling point, compared with a nearby stable reference site, is used in a regression model to determine net soil loss. The regression models of Elliott *et al.* (1990), derived from measurements on runoff-soil loss plots in Australia, have been revised in the light of errors revealed in the estimation of soil erosion from plots of the New South Wales Soil Conservation Service (Lang, 1992). The revised relationships for conditions of cultivation and grazing are:

$$SLC = 296.1\ (1.0539)^x \qquad (1)$$

$$SLG = 17.5\ (1.0821)^x \qquad (2)$$

where SLC and SLG are net soil loss under cultivated and grazing conditions, respectively, (kg ha^{-1} $year^{-1}$), and x is percentage ^{137}Cs loss, compared with the ^{137}Cs reference value.

Soil sampling for ^{137}Cs analysis was carried out along transects to a soil depth of at least 20 cm using a steel cylinder. Where the depth of cultivation was greater than 20 cm, a soil auger was used to sample below the plough depth. Reference sites were sampled by scraper-plate and frame (Campbell *et al.*, 1988), and/or multiple coring. The transects were surveyed and details of site history and physical characteristics were obtained.

The soils were analysed for ^{137}Cs using hyperpure germanium detectors, and counting errors (± 1 SD) were maintained below 5%. Caesium-137 values were plotted on transect profiles and equations (1) or (2) were used to calculate net soil loss at each sampled point. The mean net soil loss for the transect was calculated from the average of the losses, weighted for the sample spacing along the slope.

Two difficulties were encountered. Firstly, many of the cultivated sites had been operated in rotation with grazing/fallow. While information on the number of and timing of rotations was available for many sites, it was insufficient to construct a universally applicable model to apportion ^{137}Cs loss according to the timing of land use/management rotations. Therefore, it was decided that if a site had been cultivated since ^{137}Cs fallout had commenced, the regression model (equation (1)) for cultivated soils should be applied. At sites where cultivation had never taken place, equation (2) was used. Secondly, there were some transect sampling points which had ^{137}Cs loadings in excess of the reference value. Because equations relating net soil gain to ^{137}Cs gain have yet to be established for Australian soils, equations (1) and (2) were used in reverse-mode to calculate a soil "deposition" rate. In these cases, SLC and SLG are net soil "gain" and x is percentage ^{137}Cs "gain" in relation to the reference value. Although this approach is flawed, it at least permits some allowance for ^{137}Cs gain. A mean, weighted, net soil loss for each transect was calculated by subtracting soil "gains" from "losses", and these results (t ha^{-1} $year^{-1}$) are reported here.

RESULTS AND DISCUSSION

South Australia

Twelve sampling locations were included in the programme, 11 within the South Australian wheat belt, and one potato paddock in the central Mt Lofty Ranges (Fig. 1) (Moore & Ciganovic, 1995). Mean annual rainfalls range from 344 mm (Location 7) to 821 mm (Location 11), and all sampled locations are characterized by duplex soils with either sandy or sandy loam topsoils (Table 1). Estimated net soil losses were between zero and 8.16 t ha^{-1} $year^{-1}$ (Table 1). At Location 11, over the period 1960 to 1992, seven potato crops have been harvested in rotation with improved pasture and, if it is assumed that all erosion occurred during the potato phases, the average net soil loss per crop is 12.8 t ha^{-1} $year^{-1}$ (Moore & Ciganovic, 1995).

Greatest soil losses appear to be associated with sandy soils subject to both to wind and water erosion (Locations 1, 2, 10, 11 and 12). At Location 1, Cleve on the Eyre Peninsula, there were well defined sand drifts across the transect (Moore & Ciganovic, 1995). High soil loss rates at the potato rotation site (Location 11, Woodside), with an average net soil loss of 2.56 t ha^{-1} $year^{-1}$, and 12.8 t ha^{-1} $year^{-1}$ under potatoes, can be attributed to land use, slope gradient and rainfall. This location had the steepest slope (7%) and greatest mean annual rainfall (821 mm) of all locations sampled in South Australia (Moore & Ciganovic, 1995).

Victoria

Twenty locations within Victoria were sampled by the Centre for Land Protection Research and three by Saynor (1994) and Curtis (1995) together (Table 2, Fig. 1) (Lorimer *et al.*, 1995). Rotational cropping lands in northwestern and central Victoria accounted for 14 of the study districts, but the mostly forested eastern part of the state was not included in the survey (Fig. 1).

Mean net soil losses ranged from zero to 14.26 t ha^{-1} $year^{-1}$ (Table 2), with highest erosion rates in the northwestern cropping lands (The Mallee and Wimmera) and at Locations 16 and 13. The latter (Ballarat), has a potato rotation land use. Wind and water erosion are probably responsible for the high rates in the northwest (Lorimer *et al.*, 1995). There was little evidence from the ^{137}Cs results that serious erosion had occurred on grazed slopes, despite steep gradients in some cases. In these instances mass movement was recorded, however.

New South Wales

Four locations with land uses ranging from potato rotation, vineyards and grazing were studied by Saynor (1994), Surjan (1994) and Curtis (1995) (Fig. 1, Table 3). The ^{137}Cs results indicated that least erosion had occurred under grazing (0.07 to 1.5 t ha^{-1} $year^{-1}$), while both viticulture and rotational potato cropping exhibited severe losses. At Pokolbin, in the lower Hunter valley, soil erosion under vines was nearly 30 times greater than under nearby native forest (Surjan, 1994). Curtis (1995) showed that rates

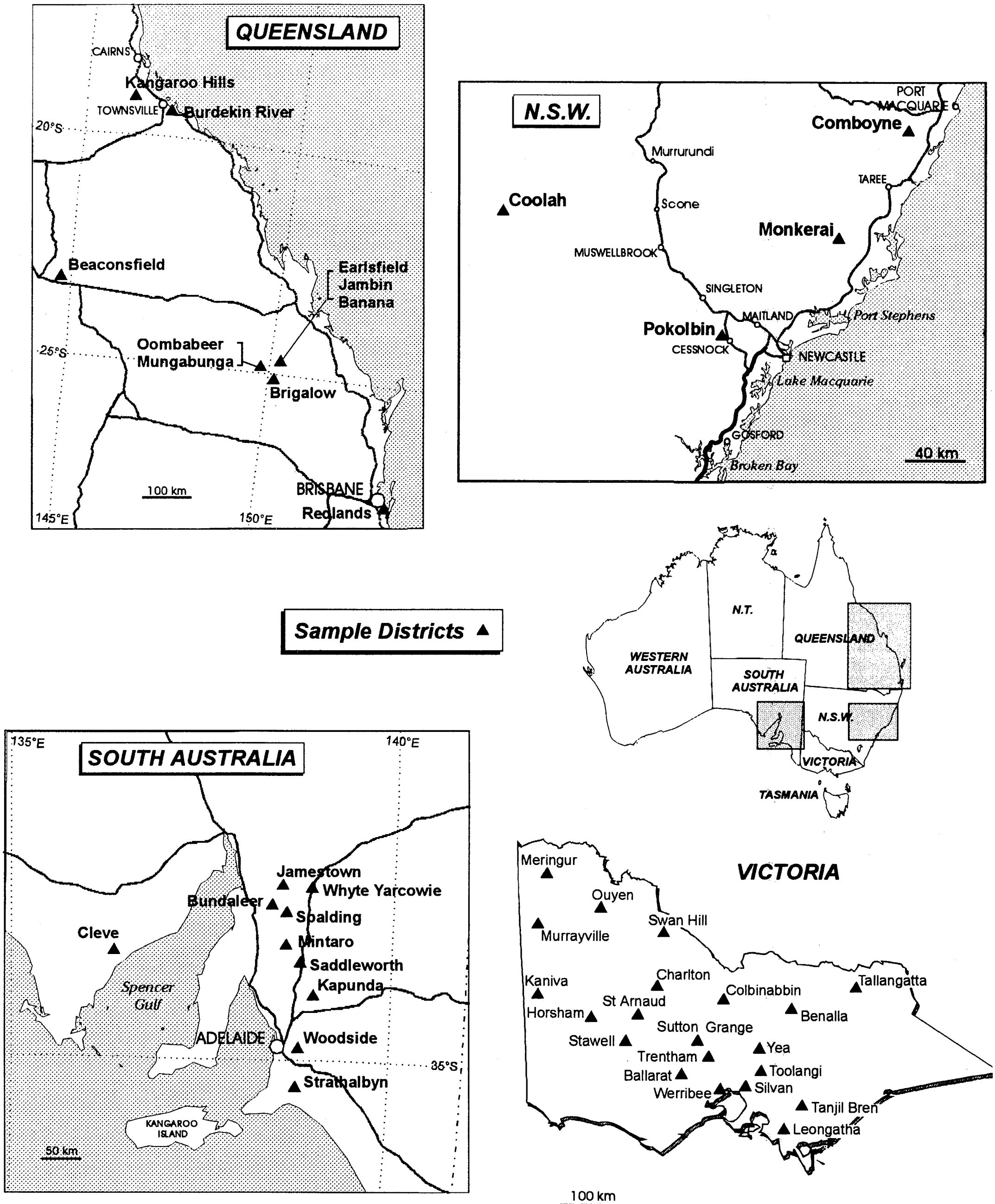

Fig. 1 Soil sampling locations in South Australia, Victoria, New South Wales and Queensland.

of soil loss under potato/pasture rotation can be as much as 48 times greater than under grazing on similar slopes on krasnozem soils in the high rainfall region of Comboyne (1860 mm year^{-1}). Two blocks of land used for a grazing/potato rotation, one upslope

Table 1 South Australia: location details and net soil loss.

Location	Mean annual rainfall (mm)	Land use	Net soil loss (t ha^{-1} $year^{-1}$)
1 Cleve	400	Wheat/sheep	8.16
2 Cleve	400	Wheat/sheep	0.40
3 Cleve	400	Wheat/sheep	1.48
4 Jamestown	464	Wheat/sheep	0.00
			0.72
			0.20
5 Spalding	442	Wheat/sheep	0.57
6 Bundaleer	450	Wheat/sheep	0.26
7 Whyte Yarcowie	344	Wheat/sheep	0.64
8 Mintaro	550	Wheat/sheep	1.34
9 Saddleworth	496	Wheat/sheep	1.25
10 Kapunda	494	Wheat/sheep	1.98
11 Woodside	821	Potatoes/pasture	2.56
		Potatoes	12.80
12 Strathalbyn	495	Wheat/sheep	3.00

Source: Moore & Ciganovic (1995).

Table 2 Victoria: location details and net soil loss.

Location	Mean annual rainfall (mm)	Land use	Net soil loss (t ha^{-1} $year^{-1}$)
1 Swan Hill	335	Cropping/pasture	14.26
2 Ouyen	250	Fallow/wheat/pasture	7.73
3 Meringur	278	Cropping/sheep	0.57
4 Suttom Grange	600	Wheat/oats/pasture	1.70
5 Murrayville	300	Cropping/sheep	4.17
6 Kaniva	457	Wheat/oats/clv	4.01
7 Horsham	420	Cropping/fallow	0.52
8 Toolangi	1500	Fruit/vegetable/pasture	0.00
9 Yea	643	Grazing	0.90
10 Charlton	400	Cropping/grazing	0.89
11 St Arnaud	584	Cropping/sheep	1.41
12 Werribee	473	Cropping/grazing	0.02
13 Ballarat	800	Potatoes/sheep	4.89
14 Stawell	584	Grazing	0.00
15 Trentham	1000	Potatoes/sheep	1.92
16 Colbinabbin	457	Cropping/sheep	3.06
17 Tallangatta	735	Grazing	0.00
18 Benalla	800	Grazing/sheep	0.89
19 Tanjil Bren	1842	Woodland	1.90
20 Leongatha	1100	Grazing	0.60
21 Yea Transect A	643	Grazing	0.36
22 Tea Transect B	643	Grazing	0.00
23 Silvan	1200	Grazing	0.68
24 Silvan	1200	Dairying/vegetables/cropping	3.35

Sources: Lorimer *et al.* (1995);
21 and 22 Saynor (1994);
23 and 24 Curtis (1995).

Table 3 New South Wales: location details and net soil loss.

Location	Mean annual rainfall (mm)	Land use	Net soil loss (t ha^{-1} $year^{-1}$)
Pokolbin	784	Vineyards	9.0
Pokolbin	784	Vineyards	13.8
Pokolbin	784	Forest	0.5
Pokolbin	784	Grazing	0.2
Pokolbin	784	Grazing	1.5
Monkerai	1288	Grazing	0.1
Monkerai	1288	Grazing	0.1
Coolah	657	Grazing	0.51
Coolah	657	Grazing	1.20
Comboyne Block A	1860	Potatoes/grazing	3.48
		Potatoes	44.8
Comboyne Block B	1860	Potatoes/grazing	1.0
		Potatoes	12.4
Comboyne	1860	Grazing	0.07

Sources: Pokolbin (Surjan, 1994), Monkerai (Saynor, 1994) and Comboyne (Curtis, 1995).

of the other, had net soil losses of 3.38 t ha^{-1} $year^{-1}$ (upslope Block A) and 1.0 t ha^{-1} $year^{-1}$ (lower slope Block B). If it is assumed that net soil loss under grazing conditions is zero, net soil loss from Block A is 44.8 t ha^{-1} $year^{-1}$, while from Block B it is 12.4 t ha^{-1} $year^{-1}$ while under potato cultivation. It was estimated that approximately 87% of the eroded soils from both Blocks A and B had accumulated in alluvial fans at the slope base (Curtis, 1995).

Queensland

The survey included 13 locations within Queensland (Fig. 1). Nine of the locations were of grazing land use of varying types and intensities, with the remaining four under wheat, sorghum and fallow rotations, and vegetable cropping/pasture rotation (Table 4) (Elliott *et al.*, 1996). Net soil losses ranged from zero to 14.7 t ha^{-1} $year^{-1}$, with the three highest rates (>5 t ha^{-1} $year^{-1}$) under cropping of different types (Table 4). One grazed location (8: Beaconsfield 1) had an estimated net soil loss of 4.1 t ha^{-1} $year^{-1}$.

CONCLUSIONS

As with any survey of soil erosion using the ^{137}Cs technique, the setting of a reference value is crucial. Other uncertainties include the accuracy of the model used to translate the ^{137}Cs loss into net soil loss, and the sufficiency of soil sampling points to characterize the site under study. Throughout the survey, similar methods were employed, so comparative values in relation to land use probably give a realistic picture.

Table 4 Queensland: location details and net soil loss.

Location	Mean annual rainfall (mm)	Land use	Net soil loss ($t\ ha^{-1}\ year^{-1}$)
1 Earlsfield	690	Wheat/sorghum/fallow	5.5
2 Jambin	575	Scrub grazing/impr. pasture	0.36
3 Oombabeer	670	Native grazing	2.5
4 Mungabunga	670	Wheat	1.3
5 Brigalow crop	650	Sorghum/wheat	14.7
6 Brigalow scrub	650	Scrub	0.0
7 Banana	700	Native grass	0.1
8 Beaconsfield 1	442	Grazing	4.1
9 Beaconsfield 2	455	Limited irregular grazing	2.0
10 Burdekin 1	893	Light grazing	0.01
11 Burdekin 2	893	Light grazing	0.0
12 Redlands	1250	Vegetables/pasture	9.0
13 Kangaroo Hills	640	Grazing	1.9

Source: Elliott *et al.* (1996).

The reconnaissance survey revealed that the range of net soil loss values was approximately the same within each state despite regional variations in climate and soil conditions. Perhaps not unexpectedly, the most serious losses were from horticultural lands (vegetables and vineyards), potato lands and broadacre grain farming, while grazing and forested areas showed, with some exceptions, minimal net soil losses.

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