Mapping drainage basin sediment sources using caesium-137

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ABSTRACT

Soil sampling on a 10 x 10 m grid pattern in two vineyard blocks within the Maluna Creek drainage basin (1.7 km²) in New South Wales was carried out for ^{137}Cs analysis; the grid represented a 4% sample of all vineyards in the basin. Lines of equal ^{137}Cs content, isocaes, were plotted and compared with ^{137}Cs values at input sites on nearby hilltops from which levels of ^{137}Cs loss from the vineyards were calculated. Regression equations relating soil loss to ^{137}Cs loss from runoff-erosion plots in eastern NSW enabled the plotting of isolines of net soil loss in the two vineyard blocks. Net soil loss rates were 6.76 t ha^{-1} y^{-1} and 5.90 t ha^{-1} y^{-1}, respectively. If a mean net soil loss rate of 6.3 t ha^{-1} y^{-1} can be assumed for all vineyards in the basin, this then represented a sediment yield of 107 t y^{-1}. Over a three-year period, the drainage basin sediment yield was 85 t y^{-1}, more than 93% of which was derived from vineyard sources making up 10% of the basin area. This suggests that annual storage of sediment eroded and transported from the vineyards may be approximately 20 t.

INTRODUCTION

The isotope caesium-137 (^{137}Cs: half-life 30 years) has been recently used as an indicator of net soil loss and sedimentation on hillslopes and in drainage basins in several studies (e.g. Longmore et al. 1983; Brown et al. 1981). Walling and Kane (1984) and Loughran et al. (in press) also used ^{137}Cs as a "fingerprint" on stream-borne sediments to identify possible sources of sediment within drainage basins. In this study, the quantification of net soil loss has been attempted in two sections of a small drainage basin by measuring relative levels of ^{137}Cs in soils and by comparison, with measured sediment output at a gauging station.

Caesium-137 is a fallout product of atmospheric nuclear weapons testing. On reaching the earth's surface, ^{137}Cs becomes firmly adsorbed by the fine fraction of surface soils. Soil erosion therefore depletes ^{137}Cs levels, unlike stable sites which have experienced little or no soil loss. These stable sites are reliable indicators of ^{137}Cs input against which ^{137}Cs losses may be assessed. A model of soil-^{137}Cs redistribution by geomorphological processes in a drainage basin was developed and tested in Maluna Creek basin in the Hunter Valley, New South Wales, Australia (Campbell et al. 1982). Further work in the Maluna basin identified cultivated vineyards as the major sediment source to the stream system (Loughran et al. 1982; Loughran et al. in press), but it was not possible to determine the magnitude of these contributions. The development of a relationship between net soil loss and ^{137}Cs loss (Campbell et al. in press), together with detailed sampling in parts of the Maluna basin, have now enabled estimates of soil loss to be made.

Since cultivated vineyards are virtually the sole source of sediment in the Maluna Creek system (Loughran et al. in press), a 4% sample of vineyard blocks was selected for ^{137}Cs and soil-loss mapping. Results from this study are presented and the implications of these measurements for interpreting the sediment yield from the basin are investigated.

Maluna Creek Drainage Basin

Maluna Creek basin is located approximately 50 km west of the city of Newcastle in eastern New South Wales, on the flanks of the Brokenback Range near Cessnock. The drainage basin has an area of 1.7 km² and a mean rainfall of approximately 750 mm. Eucalypt forest and grazing land comprise 60 and 30% of the basin area respectively, and the remaining 10% is under vineyards. A detailed description of the drainage basin is given in Loughran et al. (1981).

METHODS

To assess net soil loss from two of the cultivated vineyard blocks within the Maluna basin, soil samples were collected on a grid pattern (approximately 10 x 10 m) and analysed for ^{137}Cs content. A steel cylinder, of length 20 cm, was used to obtain soil cores. The maximum depth of cultivation had been previously assessed as 15 cm (Campbell et al. 1982) and it was assumed that all the ^{137}Cs was contained within 20 cm of the surface. Soil samples were dried at 100°C, disaggregated and sieved (2 360 µm). The finer fraction (<2 360 µm) was analysed for ^{137}Cs concentration (mBq g^{-1}) using a hyperpure germanium detector. Total ^{137}Cs content of each sample was calculated per unit area of the cylinder (mBq cm^{-2}).

Point values of ^{137}Cs content were mapped for the two vineyard blocks (under Malbec and Pinot Noir vines respectively) and lines of equal ^{137}Cs content drawn (isocaes: Longmore et al. 1983). Nearby hilltops were selected as input sites for the two blocks and 20 cm core and depth-incremental soil samples were collected at one or two centimetre intervals (Campbell et al. 1982).

To calibrate ^{137}Cs levels against soil erosion, soil samples were collected from 30 runoff-erosion plots maintained by the NSW Soil Conservation Service and within the Maluna catchment (Elliott et al. 1984; Campbell et al. in press). A relationship between ^{137}Cs loss, expressed as a percentage loss compared with local input sites, and plot soil-loss (kg ha^{-1} y^{-1}) was developed. Application of the relationship to estimate soil loss must account for the intermittent transport of sediment and adsorbed ^{137}Cs. For this reason, net soil loss, rather than gross soil loss, is the preferred term.

RESULTS

Maluna Malbec Vineyard

The block of malbec vines occupies an area of 0.325 ha across a hillslope hollow running diagonally north-east to south-west (Fig. 1). During cultivation, the soil is worked into ridges along the rows of vines. Runoff is directed by these cultivation ridges to the ends of rows, but during intense runoff events drainage often breaks more directly downslope. An earth bank upslope from the vineyard prevents runoff from entering the block from adjacent grazing land. The soil type is black earth, which is self mulching and can exhibit deep desiccation cracks after prolonged dry weather. It has a high infiltration capacity (27.4 cm h^{-1}, cylinder infiltrometer with buffer ring). At the sampling sites, the average clay content (<2 µm) was 35%, and the average silt content (20-2 µm) was 24%. Caesium-137 levels were least at the top of the block and through the hillslope hollow (Fig. 1). Five sites had zero ^{137}Cs content and four had less than 10 mBq cm^{-2}. The greatest levels of ^{137}Cs were at the centre of the block and above the downslope fence (Fig. 1). Values within the vineyard were much lower than those at the hilltop input site (104 mBq cm^{-2}) and under grassland on the same soil in an adjacent paddock (Fig. 1). Isocaes of 10, 25 and 50 mBq cm^{-2} represent comparative losses of ^{137}Cs of 95, 76 and 52% respectively.

Maluna Pinot Noir Vineyard

This vineyard block has an area of 0.35 ha on a south-facing slope. The soil type is brown podzolic with an average clay (<2 µm) content of 29% and an average silt (20-2 µm) content of 17% at the 34 sampling locations (Fig. 2). The infiltration capacity was 11.8 cm h^{-1} (average of four measurements using cylinder infiltrometer with buffer ring). The lowest ^{137}Cs content was found in a zone from the north-west to south-east. Highest amounts of ^{137}Cs were in the eastern part of the block and at the central footslope section. Two core samples at hilltop input sites above the vineyard had ^{137}Cs amounts of 101.0 and 95.3 mBq cm^{-2}. Isocaes for 15, 30 and 50 mBq cm^{-2}, representing ^{137}Cs losses of 85, 70 and 40% respectively, are shown in Figure 2.

Caesium-137 loss v. Soil loss

Soil loss rates from 30 plots were available from sites in the Hunter Valley and at Gunnedah, NSW. Twenty-six of the plots are maintained by the NSW Soil Conservation Service, 24 within an area of 100 m^2. The remaining six plots are 2 m^2 in area, four of them in Maluna basin and maintained by the Geography Department, University of Newcastle (Campbell et al. in press). Caesium-137 was measured by coring within the large plots or adjacent to the small ones. Sites judged to be uneroded and on comparable soil types were sampled to determine ^{137}Cs input. Caesium-137 loss from the plots, as a percentage of local input, was regressed against soil loss (Fig. 3). For all data (n = 30)

$$S = 3.84\ C^{1.55} \qquad (r = 0.89) \qquad (1)$$

where S is net soil loss (kg ha^{-1} y^{-1}) and C is percentage ^{137}Cs loss.
Figure 3 shows five points (circled) which represent ^{137}Cs

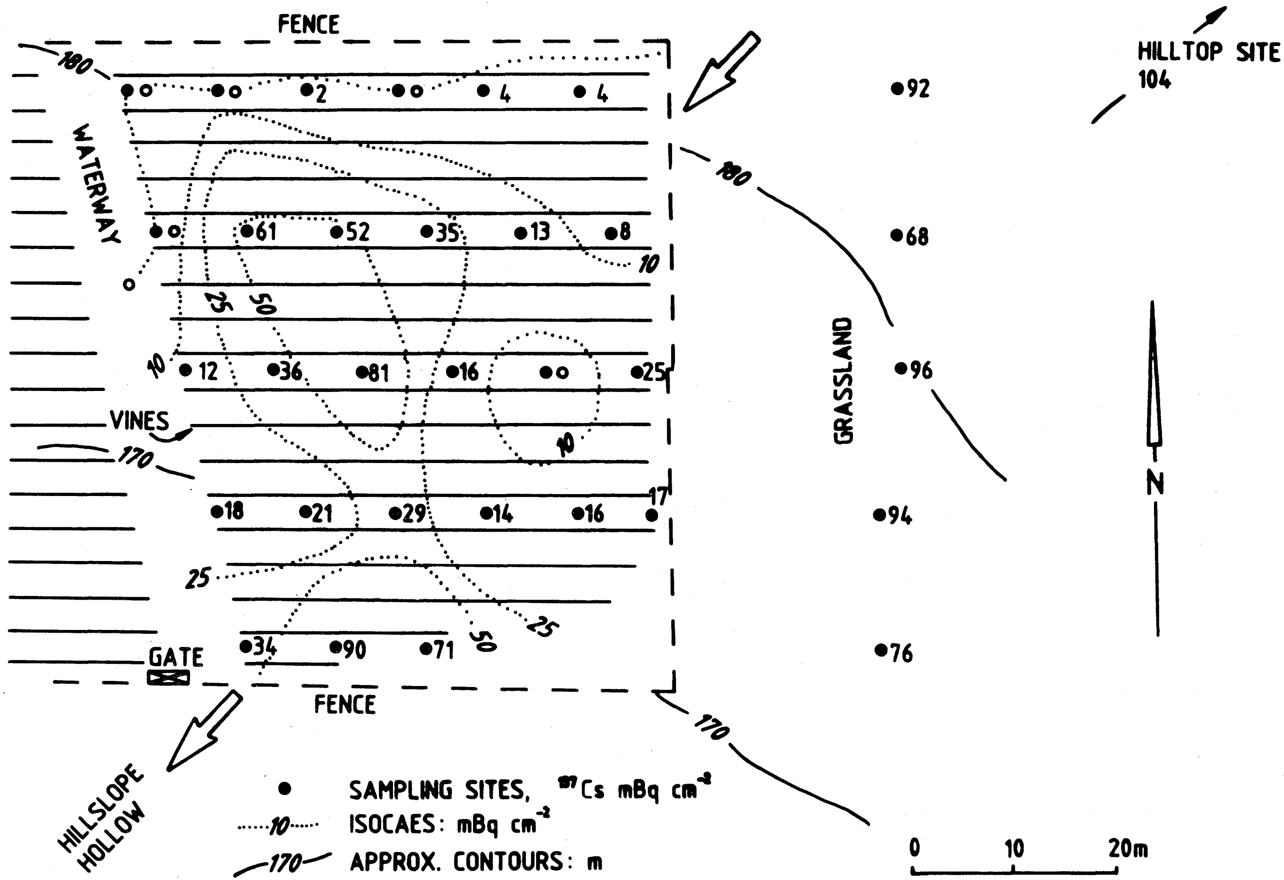

FIG. 1 Maluna Malbec Vineyard : caesium-137 distribution on soils

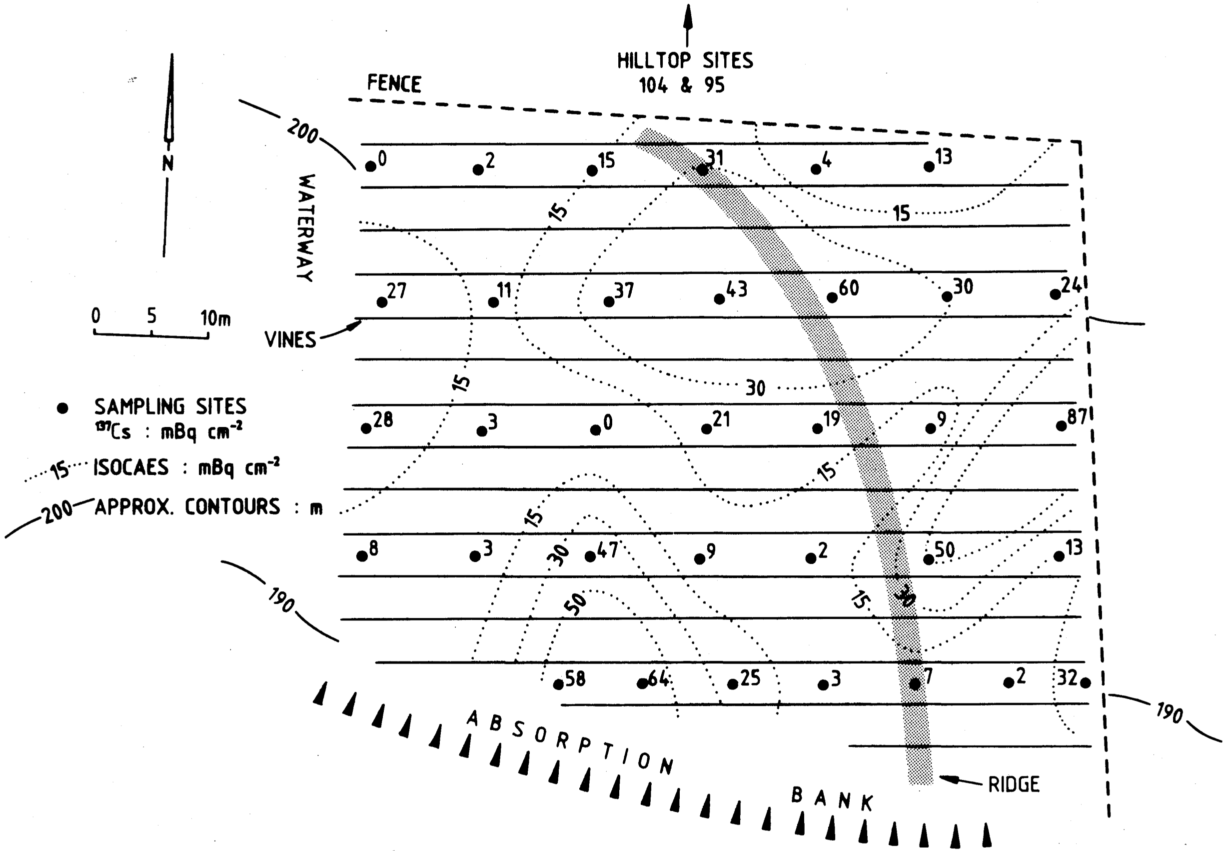

FIG. 2 Maluna Pinot Noir Vineyard : caesium-137 distribution on soils

losses above the 60% level. Since there appeared to be a steepening of the relationship in this area of the graph, the data were divided into ^{137}Cs losses below and above 60% and separate regression equations were derived.

Below 60% ^{137}Cs loss (n = 25)

$$S = 4.54\ C^{1.45} \quad (r = 0.88) \qquad (2)$$

Above 60% ^{137}Cs loss (n = 5)

$$S = 0.04\ C^{2.74} \quad (r = 0.60) \qquad (3)$$

The regression lines intersect at 41% ^{137}Cs loss.

INTERPRETATION

Maluna Malbec Vineyard

The pattern of ^{137}Cs distribution may be interpreted geomorphologically. Sites at the topmost section of the block are in positions of gross soil loss, since run-on or sediment transport from upslope is prevented by the fence, bank and grass cover. Runoff channelled to the ends of rows and down the hillslope hollow will deplete ^{137}Cs levels owing to soil erosion. Higher ^{137}Cs amounts at the lowest portion of the block are due to sedimentation. Deposition of some sediment has been observed during runoff events, and a proportion was transported through the fence and gate down the grassed waterway.

Using the hilltop site (Fig. 1) for an input value (104 mBq cm^{-2}) and equation 1, net soil losses for the isocaes shown in Figure 1 were derived. These ranged from 1 754 to 4 834 for ^{137}Cs losses of 52 and 100% respectively (Table 1). Since the highest ^{137}Cs losses appear

TABLE 1 Estimates of net soil loss from vineyards

	Isocaes of ^{137}Cs loss %	Net Soil loss (kg ha^{-1} y^{-1}) Equation 1	Equation 2 or 3
Malbec vineyard	100	4 834	12 080
	90	4 106	9 050
	76	3 160	5 695
	52	1 754	1 397
Pinot Noir vineyard	85	3 758	7 739
	70	2 781	4 546
	49	1 600	1 282

to underestimate the rate of soil erosion (Fig. 3), equations 2 and 3 were also used to calculate net soil losses for the malbec vineyard (Table 1). At the highest level, 100% ^{137}Cs loss, the net soil loss was 12 080 kg ha^{-1} y^{-1}. Figure 4A has been constructed from isocaes (Fig. 1), estimates of percentage ^{137}Cs loss (compared with input) and equations 2 and 3. The figure shows isolines of net soil loss (kg ha^{-1} y^{-1}) from the malbec block; the average net soil loss calculated from the map was 6.76 t ha^{-1} y^{-1}.

The grassed hillslope adjacent to the vineyard was sampled at

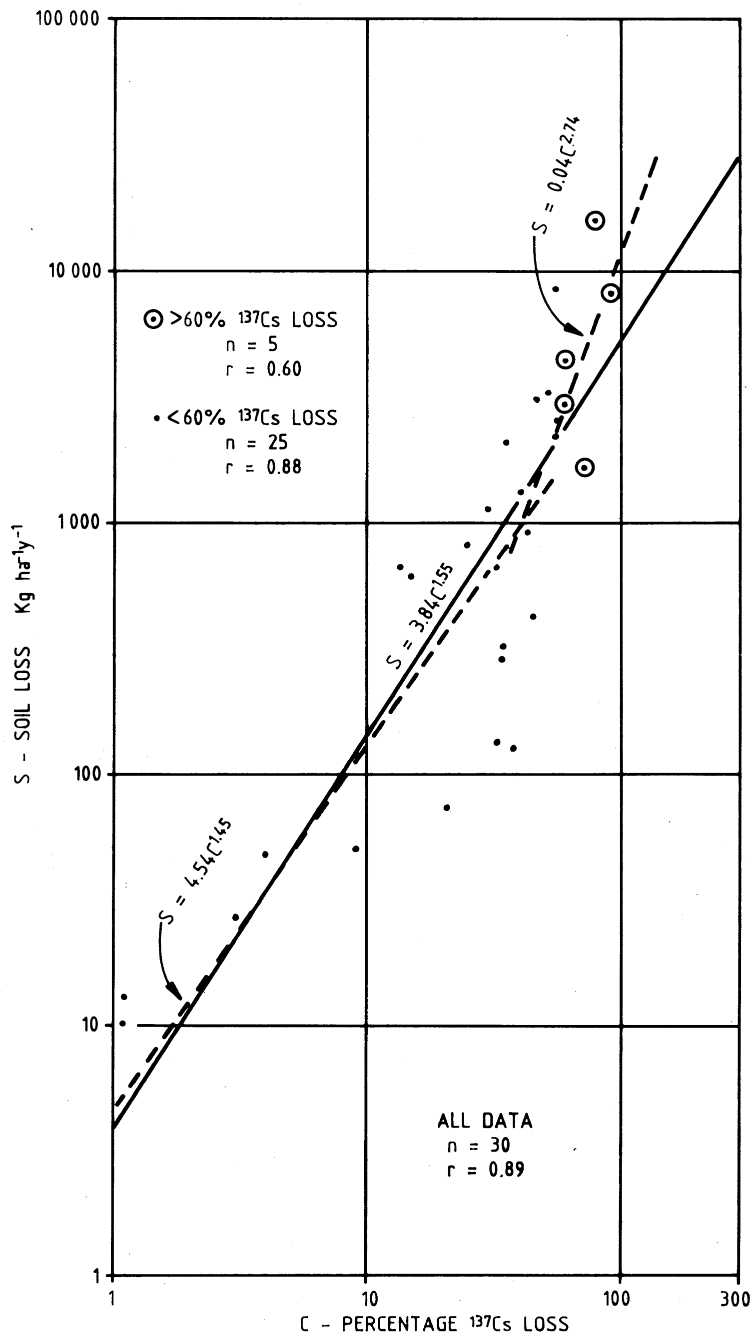

FIG. 3 Soil loss v. caesium-137 loss for runoff - erosion plots in eastern New South Wales

five points in a downslope direction, and ^{137}Cs losses were 12, 35, 8, 10 and 27% when compared with the input site (Fig. 1 and Table 2). Net soil loss at these sites was determined from equations 1 and 2, revealing that some soil movement had taken place, although it was one order of magnitude lower than in the vineyard (Table 2).

TABLE 2 Estimates of net soil loss from grassland

^{137}Cs content (mBq cm^{-2})	^{137}Cs loss %	Net Soil loss (kg ha^{-1} y^{-1}) Equation 1	Equation 2
104 (input)	0	0	0
92	12	181	167
68	35	950	691
96	8	96	93
94	10	136	128
76	27	635	540

Maluna Pinot Noir Vineyard

A similar pattern of ^{137}Cs redistribution in this block of vines was shown by the isocaes (Fig. 2). Greatest losses occurred at the top of the vineyard and downslope through the vines along two routes. At the time of sampling, rilling and minor gullying were apparent at these positions. Sediment accumulation above the soil conservation earthwork was probably responsible for the relatively high ^{137}Cs levels at the two westernmost sites in the lowest sampled row. Sampling was not carried out behind the absorption bank because quantities of sediment had been periodically removed.

Table 1 and Figure 4B show the relative levels of net soil loss within this vineyard block. As before, equations 2 and 3 were used to construct Figure 4B and estimate the average rate of net soil loss, which was 5.90 t ha^{-1} y^{-1}.

DISCUSSION AND CONCLUSION

Estimates of net soil loss from a four percent sample of Maluna vineyards provide information on sediment sources, time-averaged for a 30-year period since the onset of ^{137}Cs fallout. Assuming that this estimate (average 6.3 t ha^{-1} y^{-1}) is representative of net soil losses from the 17 ha of vineyards in the drainage basin, 107 t y^{-1} of sediment would be delivered to the stream system. There are, however, significant sediment storages within the basin which have received sediment from the vineyards, such as farm dam reservoirs, flood plains, alluvial fans and channels (Campbell et al. 1982; Loughran & Campbell 1983). Therefore, only a proportion of the estimated 107 t y^{-1} is likely to be transported from the drainage basin. For a three-year period (1978-1981) of below average rainfall (82%) 49.8 t km^{-2} y^{-1} of sediment was transported from Maluna Creek basin, a total of 85 t y^{-1} (Loughran et al. in press). It was estimated that at least 93% of this three-year sediment output was derived from vineyard sources.

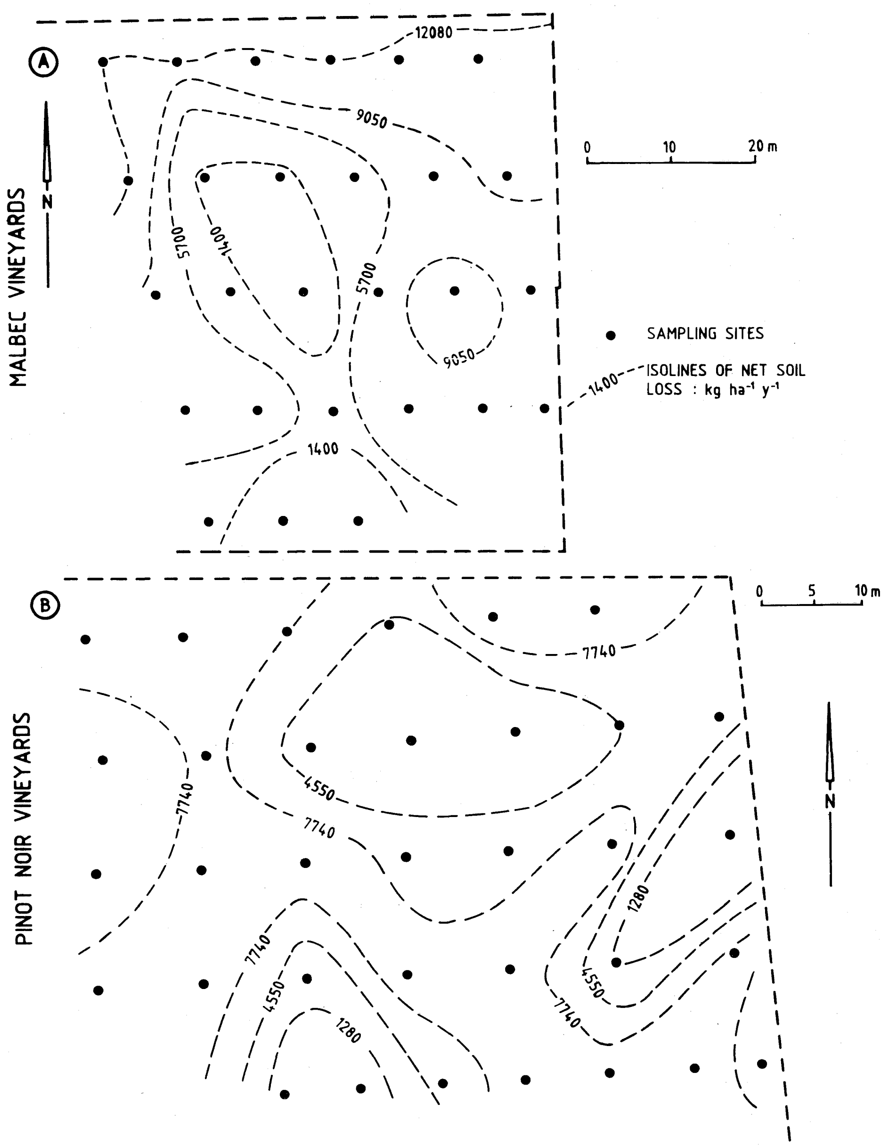

FIG. 4A Maluna Malbec Vineyard : isolines of net soil loss
FIG. 4B Maluna Pinot Noir Vineyard : isolines of net soil loss

This figure of 93% was derived from measurements of ^{137}Cs concentrations on topsoils in uncultivated (forest and grassland) and vineyard parts of the basin, compared with the ^{137}Cs concentration on stream-borne sediment collected at the basin outlet (Loughran et al. in press). Considering the assumptions and observations listed above, the estimated net soil loss from vineyards of 107 t y^{-1} is in reasonable agreement with a drainage basin sediment output of 85 t y^{-1}. This suggests that about 20 t of sediment derived from vineyard sources is stored within the drainage basin annually.

This method of estimating net soil loss takes no account of temporal variations in ^{137}Cs fallout and soil erosion. In the absence of more detailed information, this approach can give an estimate of soil loss which may be refined when additional data become available.

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