Wind Erosion in New Zealand

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1 Introduction

Aeolian processes have had a major influence in shaping the New Zealand landscape, the most visible expression being the formation of extensive, thick Quaternary and early Holocene loess deposits. These are widespread throughout both main islands of New Zealand (e.g. see Ives, 1973 and Eden and Furkert, 1988). The loess, derived from primary sources in riverbeds and coastal plains, was largely deposited under cool climate conditions of glacial periods. However, since European settlement of New Zealand large areas of the country have been converted from forest and utilised for animal grazing or crop production. As a result wind erosion became a major concern for soil conservation in New Zealand, and for a long time government subsidies were available to farmers for wind erosion control (Anon., 1971; Salter, 1984).

Climatic and soil factors, in combination with widespread vegetation degradation in parts of the country, are largely responsible for the contemporary distribution of wind erosion. New Zealand is a long, narrow landmass lying between latitudes 35E and 45ES (Fig. 1) in the zone of strong mid-latitude westerly winds, and by world standards is a windy country (Painter, 1978a). It is also mountainous, with axial ranges trending north-east/south-west across the path of the prevailing westerly winds. This results in particularly high wind speeds to the east of the mountains (Reid, 1984). Many of the soils of New Zealand have light textures (silty and sandy), are weakly aggregated, and are prone to structural decline under intensive cultivation.

This paper describes the pattern of occurrence of wind erosion and major contributing factors, summarises measured rates of wind erosion, outlines the techniques used to mitigate wind erosion hazard, and suggests research needs.

2 Distribution of wind erosion

The New Zealand Land Resource Inventory (NZLRI) provides a nationwide assessment of the distribution and severity of wind erosion based on the visual assessment technique of the land use capability mapping system (National Water and Soil Conservation Organisation, 1979; Eyles 1983, 1985). The assessment is based largely on the presence of bare ground considered to be eroding by detachment and transport by wind. The NZLRI shows contemporary wind erosion affecting 12.8% of New Zealand (Table 1), with quite different distribution patterns in the North Island and South Island (Fig. 1). The most severe wind erosion is mapped on small areas of coastal sand dunes of both islands and the volcanic plateau in the central North Island. Slight wind erosion is mapped over large areas of the South Island. Salter (1984) suggests that 27% of New Zealand is susceptible to moderate to extreme wind erosion.

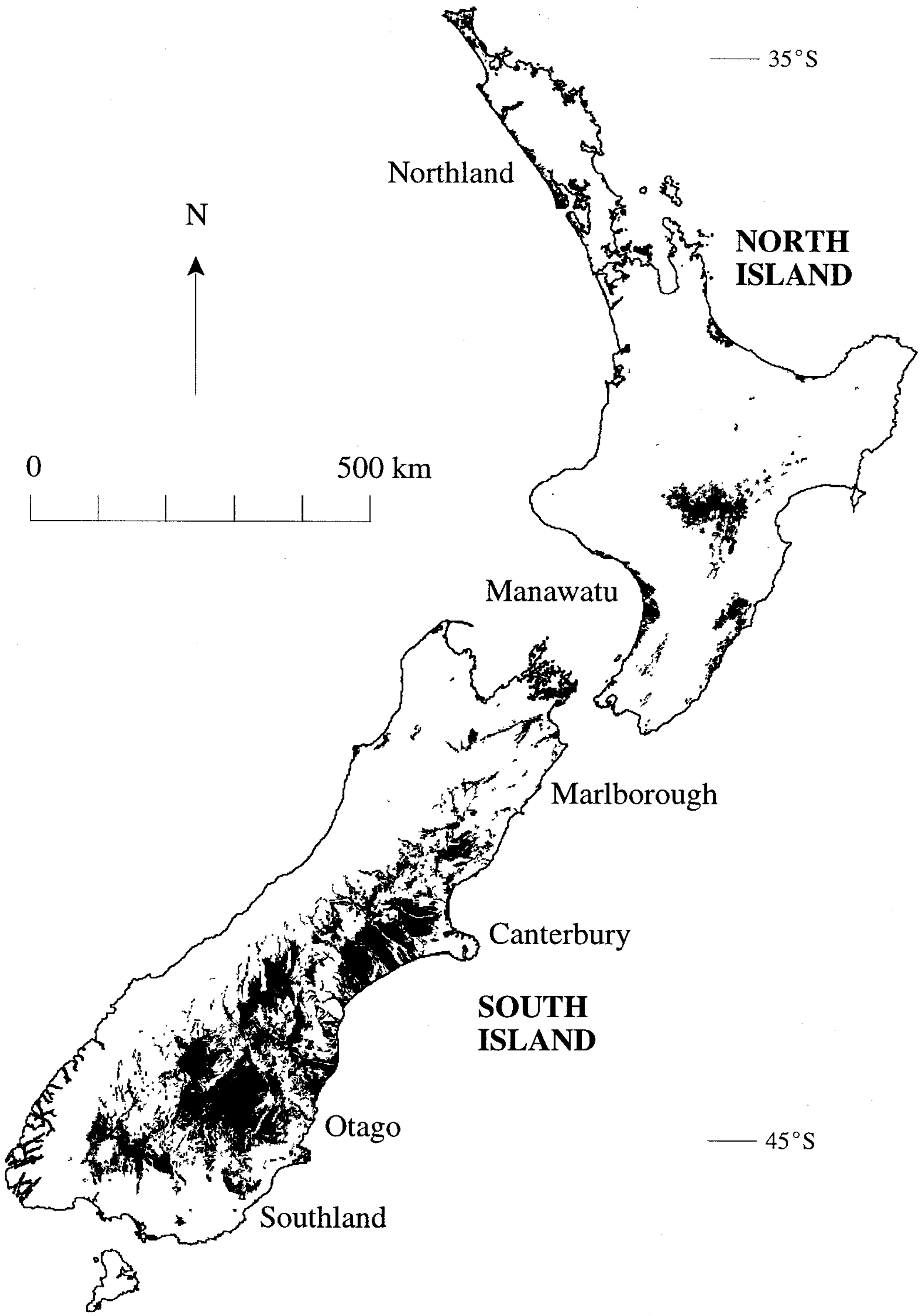

Figure 1 Contemporary wind erosion distribution in New Zealand, as mapped in the New Zealand Land Resource Inventory.

Severity (%)	Area (%) North Island	South Island	N.Z.
Slight (1-10)	2.2	13.9	8.9
Moderate (11-20)	1.1	4.1	2.8
Severe (21-40)	0.6	0.7	0.6
Very severe (41-60)	0.1	0.2	0.2
Extreme (>60)	0.5	<0.1	0.2
Total	4.6	19.0	12.8

Table 1 Extent of wind erosion in New Zealand (after Salter, 1984). Severity figures indicate the extent of bare ground represented by each class.

Wind erosion affects 4.6% of the North Island, occurring locally in three main environments:

- the mobile, coastal dunes on the west coast of Northland and the Manawatu that have not yet been afforested or have poor grass cover;
- high-altitude (>700 m), volcanic ash-mantled, gently rolling to moderately steep slopes in the central North Island that have poor vegetation cover due to frequent strong winds and cool temperatures;
- low-altitude, loess-mantled argillite hill country and alluvial terraces in the eastern North Island with low-fertility soils and severe seasonal soil moisture deficits.

In the South Island wind erosion is widespread. It is mapped over 19% of the island, mostly on loess-mantled terraces and slopes in low-rainfall, seasonally dry eastern regions subject to common strong foëhn winds. Salter (1984) recognises seven main regions where wind erosion is common:

- extensive alluvial plains in Canterbury, Marlborough and Southland with silty alluvial soils on younger terraces and loess soils on older terraces, that are susceptible to wind erosion when cultivated;
- loess-mantled downlands in Canterbury and North Otago, subject to wind erosion when cultivated;
- large inland basins in central Otago, Canterbury, and Southland with loess-mantled terraces and moraines where extensive grazing by sheep and rabbits has led to severe vegetation depletion;
- the steep, dry mountain lands of Canterbury, Otago and Marlborough with severe summer soil moisture deficits and widespread vegetation depletion;
- hill country with shallow soils, discontinuous loess cover, severe summer soil moisture deficits and localised vegetation depletion in North Canterbury;
- the exposed rolling uplands of Otago where vegetation is depleted.

3 Rates of wind erosion

While the NZLRI provides an assessment of the severity of wind erosion, it is based largely on the presence of bare ground. This provides an uncertain indication of rates of wind erosion, both for rangeland where bare ground can persist for decades and perhaps centuries (e.g. see Whitehouse, 1984), and for cropping land where bare ground and visual signs of wind erosion are short-lived. However, it is clear that wind erosion can have a severe impact on both rangeland with poor vegetation cover and cropland.

There have been few quantitative measurements of contemporary soil loss from wind erosion in New Zealand. Limited data are available for the Canterbury plains and downlands, the Manawatu plains, and the Canterbury and Otago mountain lands. Rates of wind erosion have been determined from direct measurement of short-term fluxes of material transported in suspension, post-storm measurements of soil loss in severe wind erosion events, and indirect assessments using the caesium-137 (^{137}Cs) technique (Walling and Quine, 1990). Measured rates range from a background of <0.2 t/ha/yr to storm event losses of >3000 t/ha.

Background wind transport rates have been measured directly on the Canterbury plains and in the mountain lands using mast-mounted traps. Painter (1978b) suggests that continual soil movement throughout the year on the plains at background rates results in soil losses of the order of 0.1 t/ha/yr. Butterfield's (1971) data for the mountain lands suggest background rates of 1.7 t/ha/yr.

Much of the wind erosion in New Zealand is caused by infrequent high-magnitude storms. Direct measurement of storm wind transport rates from cultivated paddocks on the Canterbury plains showed 40 kg/ha/min being eroded, with up to 5 t/ha measured in one day (Painter, 1978b). Hunter and Lynn (1988) measured soil loss from a recently planted paddock on a loess-mantled terrace in north Canterbury. Erosion was measured from the deposits at the paddock boundary. A minimum 70 t/ha (about 0.6 cm over the entire paddock) was lost from a 2.7 ha area during 2 days of strong north-west winds. Factors contributing to the severity of erosion included recent cultivation of the soil to a fine tilth, low surface soil moisture content, and very strong winds. Basher (1990) determined the amount of soil lost from a terrace in Canterbury with weakly structured, sandy soils during an extreme wind erosion event in July 1945. This storm completely stripped most of the sandy surface soil from 1.08 ha of a 6.1 ha paddock. Measurements were made of the area affected and the depth of soil lost. An average of 25 cm was removed from the eroded area, resulting in a soil loss of 3125 t/ha. This storm, with gusts exceeding 40 m/s, occurred when soils had been cultivated to a fine tilth and were very dry, and there was poor crop cover of the soil surface. McGuigan (1989) lists results from four studies of soil loss in Canterbury following severe wind erosion events in the 1970s and 80s. Measurements were made of the material deposited at paddock boundaries, and therefore probably underestimate total soil losses. Storm soil losses ranged from 20 to 125 t/ha. All the sites had been recently cultivated and/or planted, soils were silty except for one site on a peaty soil, and severe soil loss was caused by strong, dry north-west winds. In each instance the measurements were made on paddocks most affected by wind erosion.

Indirect estimates of medium-term wind erosion rates since 1953 have been made on both cropland and rangeland using the ^{137}Cs technique to provide an estimate of the net effect of erosion and deposition since 1953 (Walling and Quine, 1990). Basher and Webb (1997) describe erosion rates in rangeland subject to severe vegetation degradation in an inland Canterbury basin, where extensive bare ground and tussock pedestalling indicate active wind erosion. At six sites there was a mean soil loss of 40 t/ha/yr, or a total soil loss of 21 mm. Vegetated sites showed no evidence of soil loss, while bare soil had lost on average 80 t/ha/yr, equivalent to 38 mm of soil. Comparison of topsoil depths on pedestals and deflated areas suggested total soil losses of 40 mm.

On cropland in the loess-mantled South Canterbury downlands Basher *et al*. (1995) showed that wind erosion was redistributing soil on flat interfluves. The ^{137}Cs data suggested erosion rates up to 46 t/ha/yr and deposition rates up to 25 t/ha/yr within a single paddock, although there was no net loss of soil. Current work (Basher, in prep.) is examining rates of wind erosion on cropland on the Canterbury and Manawatu plains. At two paddocks on the Canterbury plains that were eroded in severe storms in the 1970s and 1980s, rates of wind erosion were between 13 and 15 t/ha/yr, equivalent to total soil losses over a 43-year period of 51-53 mm. In three paddocks on the Manawatu plains, rates of wind erosion were lower at 5 and 8 t/ha/yr, equivalent to total soil losses over a 43-year period of 17-24 mm. The Manawatu paddocks showed no evidence of wind erosion, other than the presence of dust clouds during cultivation, but soil structure was badly degraded owing to continuous maize cropping.

The pattern of erosion and deposition in the semi-arid rangelands of central Otago where vegetation degradation is severe was examined by Hewitt (1996). From the observed pattern of soil loss on ridges and upper sideslopes exposed to the north-west and deposition on sheltered slopes, he inferred that wind erosion was responsible for soil redistribution. An annual loss of 10.2 t/ha from exposed upper sideslopes, equivalent to a loss of 34 mm of soil, was calculated from ^{137}Cs data. Small areas on sheltered footslopes had gained 0.5-0.9 t/ha/yr, equivalent to 3-6 mm of soil. A similar pattern of soil loss related to exposure to the north-west was found in the subhumid mountain lands (Hewitt *et al*., submitted), where soil losses of 2.5-4.3 t/ha/yr, equivalent to 11-19 mm of soil, were estimated.

4 Factors influencing wind erosion

The factors affecting occurrence of wind erosion in New Zealand are similar to those elsewhere in the world. Climate (wind patterns, precipitation, frost action), soil (texture, moisture, structure, organic matter content), topography (exposure, elevation, terrain roughness, localised funnelling of wind), and cultural practices (cultivation, vegetation depletion) all influence the extent and severity of wind erosion. In the temperate climate of New Zealand, near-surface soil water content is a more important influence on wind erosion rates than in arid climates.

Wind erosivity (or, as it has been called in New Zealand, erosiveness) is the main factor controlling the broad pattern of wind erosion. It has been defined as “that property of the wind which determines its ability to entrain and move bare, dry soil in fine tilth” (Painter, 1978a). It can be estimated from daily or hourly records of wind speed above a threshold related to the lowest speed at which soil particles are entrained (Skidmore and Woodruff, 1968). Erosivity values in New Zealand are relatively high by world standards, owing to the windy climate (Painter, 1978a). Monthly erosivity values for the sites at which suitable hourly wind speed data are available commonly lie between 100 and 300 m^3/s^3. By comparison, monthly values for the USA (derived from data in Skidmore and Woodruff, 1968) commonly lie between 10 and 100 m^3/s^3 (Painter, 1977).

A factor related to climate that influences wind erosion is evaporative energy supply, which acts to reduce near-surface soil water content. It is related to wind erosivity, as it depends on advected energy in the wind, but it also depends on radiant solar energy. There have been many examples of severe wind erosion where northwesterly foëhn winds dry out cropland east of the main mountain ranges over a period of one or more days, then begin to move soil if they are of sufficient erosivity. The two factors of wind erosivity and evaporative energy supply explain much of the dominant spatial distribution of wind-eroded areas east of the main mountain ranges (Fig. 1).

Soil erodibility, defined as "that property of dry, particulate soil which governs its entrainment by wind", determines locally whether erosive winds will entrain soil particles. It can be estimated from soil aggregate size distributions by the percentage of aggregates larger than 0.84 mm (Chepil, 1950; Woodruff and Siddoway, 1965). There has been no quantitative analysis of the erodibility of New Zealand soils, but many have a low proportion of aggregates >0.84 mm owing to low clay content and weak soil structure. Most of the observed wind erosion occurs on soils derived from loess, silty alluvium, coastal sands, or young tephra, implying high erodibility for these soils. Soil types which are susceptible to wind erosion have been qualitatively identified in some regions of New Zealand (e.g. Wethey, 1984 for the Canterbury plains). Coastal sand dunes are an obvious environment where soil erodibility is high and erosion has been a major problem (Wendelken, 1974). Soil erodibility can vary over time, being influenced by weather conditions (particularly rain and frost) and land management history (cultivation). Erodibility can also be affected by recent wind erosion history causing the selective removal of certain sizes of aggregates and particles. For example, in mountain regions removal of fine soil particles by wind erosion leaves a non-erodible lag of stones on the soil surface commonly (stone pavement).

Surface soil water content at time of cultivation also influences erodibility (Cresswell *et al*., 1991). Most of New Zealand's cropping soils, used for grain, vegetable, and row-crop agriculture, are susceptible to wind erosion. But wind erosion occurs only when drying and erosive wind speeds persist long enough at locations where non-irrigated, cultivated soils have little vegetative cover. The history of rainfall, irrigation, and evaporation, together with the soil water holding capacity and resistance to evaporative flux, combine with soil erodibility (for dry, particulate soil) to determine whether soil will erode. It is this factor which ensures that wind erosion is a less significant phenomenon in New Zealand than in the USA, in spite of the generally higher wind erosivity.

Surface vegetative cover is an important influence on rates of wind erosion on cropland and rangeland. On cropland wind erosion is most often a problem when cultivated soil, in fallow or in the early stages of crop emergence, is subject to strong, dry winds in late spring or early summer. However, cropping soils in New Zealand are often sown in pasture species as part of a crop rotation and this limits the interval during which soils are susceptible to wind erosion. Trampling by livestock can also reduce vegetation cover and contribute to erosion. For example, severe wind erosion has been recorded after grain stubble has been heavily grazed and trampled by sheep. In mid-altitude, low-rainfall tussock grasslands, which have been subjected to over-grazing and vegetation depletion, the extent of wind erosion is closely related to vegetation cover (Basher and Webb, 1997). In alpine areas, wind erosion occurs on ground left bare by the action of water or mass movement erosion, especially when freeze-thaw processes have produced erodible particles (Butterfield, 1971).

5 Hazard mitigation

Hazard mitigation depends on diminishing causative factors (e.g. reducing local wind speeds), enhancing resistance to erosion (e.g. reducing soil erodibility), or reducing the undesirable consequences of wind erosion (e.g. trapping saltating soil and returning it to source). Wind erosion control in New Zealand is dominated by the use of vegetative cover to reduce entrainment of soil particles or to provide a barrier to reduce wind velocity. There has been little use of tillage techniques, to increase surface roughness and produce non-erodible aggregates, in spite of advocacy by soil conservators (e.g. Anon., 1971). There is also greater opportunity to use irrigation to increase surface soil water content, and reduce the hazard at times when soil would otherwise be susceptible to wind erosion. Mitigation of wind-borne dust emission from rural roads, construction sites, quarries, and other industrial locations is practised, usually by spraying water or oil. Economic justification for wind erosion hazard mitigation in New Zealand has been limited to that required for the formal wind erosion control schemes, or put forward as unsubstantiated opinion (Painter, 1976; Salter, 1984).

Field shelter by planting windbreaks is widely practised for both cropland and pastoral farmland in New Zealand (Sturrock, 1984). Many windbreaks were planted and fenced for grazing control using subsidies from regional soil conservation authorities (e.g. Stringer, 1978; Wethey, 1984) and were often planted as part of regional wind erosion control schemes. By 1984 1.9 million hectares of land susceptible to wind erosion was protected by wind erosion control schemes (Salter, 1984). Windbreaks have been multi-purpose, providing livestock shelter and enhanced crop growth (Sturrock, 1981) in addition to mitigating wind erosion. Windbreaks are very commonly used for horticultural and nursery crop protection. Considerable research has been directed at windbreak design and performance, suitable species, the advantages of shelter, and its costs and benefits (see Salter, 1984 and Gilchrist, 1984).

On severely eroded hill country and sand dunes, forests have been planted to mitigate wind erosion hazard (Whitehead, 1964). Most of them are eventually harvested for production purposes. Wind erosion hazard mitigation in pastoral and rangeland areas of New Zealand, including higher-elevation sheep grazing lands, is mostly by a combination of tree planting (forest woodlots and windbreaks) and vegetative cover improvement through pasture species selection, fertiliser application, and grazing management.

6 Research needs

Although the spatial extent of wind erosion in New Zealand is quite well documented, there is a need for further research to quantify rates and impacts of wind erosion. There is no data to establish the importance of nutrient and productivity losses which result from wind erosion. To be able to estimate economic effects of wind erosion and apply such results widely, research is needed into modelling of wind erosion.

Hazard mitigation is most successful when part of well integrated land management. Crop and livestock shelter, cultivation management for soil quality and nutrient conservation, amenity and aesthetic considerations are all related to wind erosion hazard mitigation. There is a need for research into best management practices that balance economic and environmental concerns, and policies which will promote them.

7 Conclusions

New Zealand is a windy country by world standards, but wind erosion is not an acutely severe problem owing to the temperate climate and dominance of rotational cropping farming systems. About 13% of the country is currently affected by wind erosion; 27% is thought to be potentially susceptible to moderate to extreme wind erosion. There are limited data available, from single event measurements or indirect assessments using caesium-137, to estimate rates of wind erosion. Measured rates range from background rates of < 0.2 t/ha/yr to storm event losses > 3000 t/ha.

Surface soil water content is a more important influence on wind erosion in New Zealand's temperate climate than in more arid climates. Likewise, evaporative energy supply is a major cause of erosion, because it reduces near-surface soil moisture. Tillage practices complementary to macro shelter have been advocated, but have not been used much in New Zealand.

There is a need for further research on modelling wind erosion, and on nutrient and productivity losses caused by wind erosion. Hazard mitigation should be integrated with best land management practices for reasons other than wind erosion. Policy which allows this to happen must be found, as current net soil losses are unsustainable.

References

Anon. 1971: Wind erosion control. *Soil and Water* 8: 23-27.

Basher, L.R. 1990: Wind erosion and soil re-formation in the upper Hurunui River gorge. *Division of Land and Soil Sciences Technical Record* CH6, Department of Scientific and Industrial Research, Christchurch, New Zealand.

Basher, L.R., Matthews, K.M., Zhi, L. 1995: Surface erosion assessment in the South Canterbury downlands, New Zealand using ^{137}Cs distribution. *Australian Journal of Soil Research* 33: 787-803.

Basher, L.R. and Webb, T.H. (1997): Wind erosion rates on terraces in the Mackenzie Basin. *Journal of the Royal Society of New Zealand* 27: 499-512

Butterfield, G.R. 1971: The susceptibility of high country soils to erosion by wind. Pp. 329-334 in *Proceedings of the Seminar on Catchment Control in New Zealand, Massey University*, New Zealand Association of Soil Conservators, Palmerston North, New Zealand.

Chepil, W.S. 1950: Properties of soil which influence wind erosion: II. Dry aggregate structure as an index of erodibility. *Soil Science* 69: 403-414.

Cresswell, H.P., Painter, D.J., Cameron, K.C. 1991: Tillage and water content effects on surface soil physical properties. *Soil and Tillage Research* 21: 67-83.

Eden, D.N. and Furkert, R.J. (Eds) 1988: *Loess: its distribution, geology and soils*. Proceedings of an International Symposium on Loess, New Zealand, 14-21 February 1987. A.A. Balkema, Rotterdam.

Eyles, G.O. 1983: The distribution and severity of present soil erosion in New Zealand. *New Zealand Geographer* 39: 12-28.

Eyles, G.O. 1985: The New Zealand Land Resource Inventory Erosion Classification. *Water and Soil Miscellaneous Publication* No. 85. Ministry of Works and Development, Wellington.

Gilchrist, A.N. 1984: Wind erosion hazard and its mitigation by shelter: a review. *Publication No. 6*, Soil Conservation Centre, Ministry of Works and Development, Palmerston North, New Zealand.

Hewitt, A.E., Lynn, I.H., Cuff, J.R.I. (submitted): Surface erosion estimation using ^{137}Cs in steeplands, Omarama, New Zealand. *Australian Journal of Soil Research*

Hewitt, A.E. 1996: Estimating surface erosion using ^{137}Cs at a semi-arid site in Central Otago, New Zealand. *Journal of the Royal Society of New Zealand* 26: 107-118.

Hunter, G.G. and Lynn, I.H. 1988: Wind erosion of a soil in North Canterbury. *New Zealand Journal of Experimental Agriculture* 16: 173-177.

Ives, D.W. 1973: Nature and distribution of loess in Canterbury, New Zealand. *New Zealand Journal of Geology and Geophysics* 16: 587-610.

McGuigan, F.J. 1989: Wind erosion on the Canterbury Plains October 1988. Report to North Canterbury Catchment Board and Regional Water Board, Christchurch, New Zealand (unpublished).

National Water and Soil Conservation Organisation 1979: *Our Land Resources*. Ministry of Works and Development, Wellington.

Painter, D.J. 1976: What cost wind-blown soil. *New Zealand Farmer* 97: 47-48.

Painter, D.J. 1977: Wind erosiveness summaries for New Zealand sites. *Project Report* P/15, New Zealand Agricultural Engineering Institute, Lincoln College, Canterbury, New Zealand.

Painter, D.J. 1978a: Wind erosiveness in New Zealand. *New Zealand Journal of Science* 21: 137-148.

Painter, D.J. 1978b: Soil erosion rates on New Zealand farm land. Pp. 25-42 in *Proceedings of the Conference on Erosion Assessment and Control in New Zealand,* New Zealand Association of Soil Conservators, Christchurch.

Reid, S.J. 1984: Wind hazard. Pp. 66-69 in Speden, I. and Crozier, M.J. (compilers) *Natural Hazards in New Zealand*, New Zealand National Commission for Unesco, Wellington.

Salter, R.T. 1984: Wind erosion. Pp. 206-248 in Speden, I. and Crozier, M.J. (compilers) *Natural Hazards in New Zealand*, New Zealand National Commission for Unesco, Wellington.

Skidmore, E.L., and Woodruff, N.P. 1968: Wind erosion forces in the United States and their use in predicting soil loss. *Agriculture Handbook No. 346*, United States Department of Agriculture Agricultural Research Service.

Stringer, D.J. 1978: Controlling wind erosion in South Canterbury. *Farm Forestry* 20: 33-39.

Sturrock, J.W. 1981: Wind constraints to agricultural productivity. *Weather and Climate* 1: 31-35.

Sturrock, J.W. (Ed.) 1984: Shelter research needs in relation to primary production: report of the National Shelter Working Party. *Water and Soil Miscellaneous Publication* 59, Ministry of Works and Development, Wellington.

Walling, D.E., and Quine, T.A. 1990: Calibration of caesium-137 measurements to provide quantitative erosion rate data. *Land Degradation and Rehabilitation* 2:161-175.

Wendelken, W.J. 1974: The New Zealand experience in stabilisation and afforestation of coastal sands. *International Journal of Biometeorology* 18: 145-158.

Wethey, D.C. 1984: *Regional Windbreak Scheme, 1984 Review.* North Canterbury Catchment Board and Regional Water Board, Christchurch.

Whitehead, P.S. 1964: Sand dune reclamation in New Zealand. *New Zealand Journal of Forestry* 9: 146-153.

Whitehouse, I.E. 1984: Erosion in the eastern South Island high country - a changing perspective. *Journal of the Tussock Grassland and Mountain Lands Institute, Review* 42: 3-23.

Woodruff, N.P. and Siddoway, F.H. 1965: A wind erosion equation. *Soil Science Society of America Proceedings* 29: 602-608.