PROCEEDINGS OF THE AUSTRALIAN RANGELAND SOCIETY BIENNIAL CONFERENCE

Official publication of The Australian Rangeland Society

Form of Reference

The reference for this article should be in this general form;
Author family name, initials (year). Title. *In*: Proceedings of the nth Australian Rangeland Society Biennial Conference. Pages. (Australian Rangeland Society: Australia).
For example:
Anderson, L., van Klinken, R. D., and Shepherd, D. (2008). Aerially surveying Mesquite *(Prosopis* spp.) in the Pilbara. *In*: 'A Climate of Change in the Rangelands. Proceedings of the 15th Australian Rangeland Society Biennial Conference'. (Ed. D. Orr) 4 pages. (Australian Rangeland Society: Australia).

The Australian Rangeland Society

COVER LEVELS TO CONTROL SOIL AND NUTRIENT LOSS FROM WIND EROSION ON SANDPLAIN COUNTRY IN CENTRAL N.S.W.

John F. Leys

Department of Conservation and Land Management
P.O. Box 363, Buronga, N.S.W. 2739

ABSTRACT

Grazing pressure resulting from high stocking levels can change the surface cover levels and soil crust enough to dramatically increase the erosion hazard of a paddock. For the sandplain country west of Cobar, percentage live vegetation plus percentage litter(*%veg+lit*) was found to explain 77 % of the variation in wind erosion (*Q*). Erosion hazard could be greatly reduced if > than 54 % of cover (*%veg+lit*) can be maintained.

For a 75 km/hr wind, erosion rates of 6.78 t/ha/min were measured with a portable wind tunnel for the highest stocking rate (4 goats/ha). By reducing stocking rate to 1 goat/ha erosion rates fell 91.3 % and by reducing to 0.7 goats/ha erosion rates were 99.7 % less than the highest stocking rate.

Wind erosion removed significant quantities of nutrient from the sandhills in the 4 goats/ha paddock. If nutrients were to be replaced as fertiliser, it would cost $0.69/ha/min for the 4 goats/ha treatment, and $0.08/ha/min for the 1 goat/ha treatment for a 75 km/hr wind.

INTRODUCTION

During 1991-92, western New South Wales has experienced numerous dust storms and the pictures of drought effected land and dead sheep have been spread across the pages of the national papers. These drought conditions and the associated wind erosion have occurred many times before in the Australian rangelands.

Sturt, during his 1844 expedition, reports (Brock 1875, p54) that one evening his camp was nearly buried by drifting sand in country which to that date had no domestic stock. Devastating dust storms in the rangelands have been reported for the last one hundred years. Condon (1976), reports major dust storms in the 1890's and Ratcliff (1935) during the 1930's. More recently Mctainsh *et al.* (1990, their Fig.2) have shown that dust storm frequency in eastern Australia, for the period 1960-84, is highest in the semi-arid rangelands.

Reduction in pasture cover levels was identified by Newman and Condon (1969) and Noble and Tongway (1986) as the primary cause of wind erosion in the rangelands. Marshall (1972), Johns *et al.* (1984) and Leys (1991) all concluded that vegetation, and its management, are the keys to controlling wind erosion.

The maintenance of vegetation levels in the semi-arid rangelands is largely dependent on grazing pressure (including native, domestic and feral animals) and seasonal climatic conditions. As land managers have no control over the weather, stocking levels are the major method of pasture level manipulation.

The aim of this paper is to describe the cover levels required to control wind erosion and nutrient loss associated with three stocking levels on the N.S.W. Agriculture's "Lynwood" grazing trial, 100 km WNW of Cobar, N.S.W. The trial is studying the effectiveness of using goats to control narrow-leaf hopbush (*Dodonaea attenuata*).

METHODS

Soils and Treatments

Three stocking rates and a range of landform units within each paddock were assessed during December 1990. They were :

1. Blitz : very high stocking rate (4 goats/ha) over 10 months. Two land units were assessed (i) sandhill (BH) and (ii) flat (BF).
2. High : high stocking rate (1 goat/ha) for 30 months. Four land units were assessed (i) sandhill with grass/forb cover (HH); (ii) sandplain with grass/forb cover (HS); (iii) sandhill with red box (*Eucalyptus intertexta*) (RH); and (iv) sandplain with red box (RS).
3. Moderate : moderate stocking rate (0.7 goats/ha) for 30 months. Two land units were assessed (i) sandhill (MH) and (ii) flat (MF).

The sandhills and sandplains had loamy sand surface textures, (Northcote (1979) classification of Uc5.21) and the flats were a fine sandy clay loam (Gn2.12).

A total of 22 sites were selected in the blitz goat treatment (Blitz), 47 sites in the high goat paddock (Hgoat) and 13 sites in the moderate goat paddock (Mgoat). Wind tunnel simulations were carried out on a range of cover levels from 0 to approximately 95% cover over the three paddocks.

Soil and wind speed measurements

For each site a portable wind tunnel (Raupach and Leys 1990) was used to measure the relationship between soil erosion, wind velocity and vegetation cover levels. The methodology was to run the wind tunnel for 60 seconds at a range of wind speeds (between 15 and 75 km/h).

Mean wind speed (u) was measured with a pitot static tube of diameter 0.2 mm connected to a differential pressure transducer. The resultant output voltages from each transducer are proportional to the local dynamic pressure (p_d). Mean velocity (u) was calculated using the form $u = (2p_d/p)^{\frac{1}{2}}$ (where p is the air density, inferred from the ambient atmospheric pressure and the air temperature measured inside the tunnel).

Measurements of soil and dust (material < 75 µm) transport were made in the wind tunnel with a modified Bagnold sand trap (Bagnold, 1941) of height 500 mm and width 5 mm, connected to a vacuum cleaner containing a pre-weighed clean filter bag.

Horizontal soil transport rate was described by soil flux, $Q = m / (TY)$ where m = mass of soil accumulated in the vacuum bag after a time interval T (60 sec) and Y is the trap width (0.005 m). The soil erosion rate was calculated by the form $ERO = m / (TFY)$ where F = fetch of soil upwind of sand trap (4.2 m). The determination of the dust erosion rate was calculated by the form $FINERO = \%FINES \times ERO$. The level of $\%FINES$ is the percentage of soil < 75 µm as determined by detailed particle size analysis (PSA).

Soil characteristics for each site included, PSA of the soils and wind eroded sediments, soil cloddiness (*%DA*, mass percentage of dry aggregates with diameter greater than 0.85 mm using the method of Semple and Leys (1987)) and nutrient analysis of the soils and eroded sediments. Nutrient analyses included total nitrogen by the modified Kjeldahl method (Page *et al.* 1982); total phosphorus using sodium carbonate extract (Page *et al.* 1982); organic carbon by the Walkley-Black method (Page *et al.* 1982).

Cover assessments

The wind tunnel sites were photographed after each run. Slide photographs were taken vertically of four 1 m^2 quadrats equally spaced down the length of the tunnel coverage. The slide photographs were projected onto a 100 square grid overlay and the percentage of vegetation cover (live perennial and ephemeral, *%veg*), surface litter (leaves and twigs, *%lit*), loose soil (*%eromat*) and surface crusting (*%crust*) were calculated.

Nutrient loss and cost

The nutrient loss (in kg) was calculated by multiplying the erosion rate of the dust (*FINERO* kg/ha/min) for the maximum wind velocity in the wind tunnel (12 m/s at 15 cm height) by the nutrient concentration ($\%NC_d$) of the dust (material < 75µm) giving the nutrient loss in kg/ha/min.

One cost of wind erosion is the amount and cost of fertiliser product required to replace the nutrient lost in the dust. Firstly, the amount of fertiliser product (kg/ha) required to replace the lost nutrients was calculated by dividing the nutrient loss (in kg/ha) by the nutrient concentration of the fertiliser product. Secondly, the cost ($/ha) of the fertiliser required to replace the lost nutrients was calculated by multiplying the amount of fertiliser (kg/ha) required by the cost of the fertiliser ($/kg).

RESULTS

Cover and soil surface conditions

Surface conditions varied between the land units, and more markedly, between treatments (Table 1). The cover levels are represented by the live vegetation cover and litter. The combination of these two parameters (*%veg+lit*) decreased with increasing stocking rate. The Blitz treatment had the lowest cover levels because of the very high stocking rate. On the sandhill (BH) there was only woollybutt (*Eragrostis eriopoda*) butts and litter from the neighbouring red box and narrow-leaf hopbush. On the flat (BF) there was only a thin layer of annual herbage litter. The soil of BH consisted mainly of loose sandy material of 1 to 3 cm depth (*%eromat* = 60.59 %) and a small proportion of the surface (12.5 %) was covered with a compact crust where previous erosion had removed the loose sandy layer. By comparison BF was characterised by a compact crust and very prostrate annual herbage litter.

The sandhills and adjoining sandplains differed in their tree cover which had a marked effect on the pasture and litter types. The grass/forb covered sandhill and sandplain (HH and HS) were typified by the coverage of prostrate annual herbage. Both these sites showed little sign of erosion and had little crusting of the surface. In contrast, the sandhill and sandplain with red box (RH and RS) were similar to BH with scattered dead woollybutt butts and a litter of leaf fall and twigs from the red box trees. The soil surface for RH was similar to BH with a 1 to 1.5 cm loose sandy layer and small crusted areas resulting from previous erosion at the site. Crusting increased down the slope at the margin of the sandhill (RH) and the sandplain (RS) as the impact of wind erosion and sheetwash became more prevalent in removing the loose surface material.

Table 1: Soil flux levels (*Q*) for a 12 m/s wind at 15 cm height, percentage live vegetation cover levels (*%veg*), percentage litter (*%lit*), percentage dry aggregation > 0.85mm (*%DA*), percentage crust cover (*%crust*), percentage loose soil (*%eromat*) and number of samples for each treatment (n) for the three stocking levels and different land units assessed at Lynwood. Where BH= blitz sandhill; BF blitz flat; HH= Hgoat sandhill; HS= Hgoat sandplain; RH= Hgoat sandhill with red box; RS= Hgoat sandplain with red box; MH= Mgoat sandhill; and MF= Mgoat flat.

Site	n	*Q*	*%veg*	*%lit*	*%DA*	*%crust*	*%eromat*
BH	20	47.74	2.94	23.58	48.72	12.90	60.59
BF	2	0.45	1.5	48.75	79.15	35.63	0.00
HH	13	3.95	6.06	47.50	45.62	0.00	46.44
HS	15	0.61	6.35	73.77	56.89	0.00	19.88
RH	11	30.25	1.55	56.77	46.20	5.30	36.34
RS	8	46.11	2.75	41.72	54.08	10.63	44.91
MH	10	0.13	19.38	66.28	57.87	14.32	0.00
MF	3	0.22	50.50	30.92	86.70	18.48	0.00

The Mgoat treatment was considerably different because of the lower stocking rate and the resultant retention of the surface vegetation. The sandhill (MH) was covered in live woollybutt plants with foliage projecting to an average height of 20 cm. The soil between the woollybutt plants was strongly crusted with a well developed stable organic/porous layer 2 to 3 mm thick. The flat (MF) had a cover of prostrate annual herbage and a very strong crust.

Soil erosion and dry aggregation

Soil flux (*Q*), varied between stocking treatments and land units (Table 1). Erosion was greatest on the sandhills with low cover (*%veg+lit*) and with a loose sandy surface, that is sites BH and RH. As the percentage of soil cover increased, erosion rates dropped. The other sandhill in Hgoat (HH) had low erosion rates, while in Mgoat (MH) erosion rates were negligible.

The dry aggregation levels *%DA* for each land unit were similar for both Blitz and Hgoat treatment. The Mgoat *%DA* levels were higher for the land units compared to the other treatments.

Nutrient loss and cost

Soils at three depths were analysed for nutrient concentration at two sites that experienced erosion (i.e. BH and HH)(**Table 2**). Nutrient concentration decreased with depth (the exception being the 4 to 5 cm depth at the Hgoat site). The eroded sediments caught in the tunnel were sieved through a 75 µm sieve and the material that passed through the sieve (dust) was analysed for nutrients (Table 2). A 75 µm sieve was used because recent field work indicates that material < 75 µm was found to be the only size of sediment leaving wind eroded paddocks (Leys and McTainsh, unpublished data). Material > 75 µm tends to be redistributed in the paddock, therefore that soil and its nutrients are not lost from the system.

The eroded dust showed considerable nutrient enrichment, that is, the ratio of the nutrient concentration of the eroded material to the nutrient concentration of the soil the eroded sediments were derived from. The eroded sediments of BH showed enrichment ratios of approximately 2:1 for total N, total P and % organic carbon. By comparison, HH showed a ratio of 1:1 (**Table** 2).

The amounts and costs of replacing nutrients as fertiliser for two sandhill sites were calculated and are given in **Table 3**.

Table 2. The soil nutrient levels for three depths and eroded sediment (dust <75µm) nutrient concentrations for two sandhills at the Lynwood site.

Site	Land unit	Source	Total N (%)	Total P (ppm)	Organic C (%)
Blitz	sandhill	dust <75 um	0.044	642	0.742
Blitz	sandhill	0-1 cm soil	0.024	299	0.584
Blitz	sandhill	2-3 cm soil	0.018	295	0.471
Blitz	sandhill	4-5 cm soil	0.012	136	0.302
Hgoat	sandhill	dust <75um	0.028	na	na
Hgoat	sandhill	0-1 cm soil	0.026	322	0.480
Hgoat	sandhill	2-3 cm soil	0.023	295	0.275
Hgoat	sandhill	4-5 cm soil	0.016	300	0.398

na = insufficient sample to analyse

Table 3. Soil loss rates of dust (*FINERO* = material < 75 µm) and the corresponding nutrient loss rate of total nitrogen for a 12 m/s wind at 15 cm height. The equivalent amount of fertiliser and the cost of replacing the lost nutrient is given for two sandhill sites at Lynwood. Where BH = Blitz sandhill; HH = Hgoat sandhill.

Site	*ERO* kg/ha/min	%*FINES*	*FINERO* kg/ha/min	N Loss kg/ha/min	Product Required kg	Product Cost $/kg	Replacement Cost $/ha
BH	5199.2	13.5	701.9	0.31	1.72	0.40	0.69
HH	571.1	15.8	90.2	0.02	0.21	0.40	0.08

DISCUSSION

Vegetation cover

To ascertain which factors had the greatest affect on soil flux (Q), a stepwise multiple regression (SAS 1988) (with the f statistic to enter set at $P<0.15$) was performed on the cover factors that reduced erosion in Table 1. The best three variable model using all the data (n = 82) explained 82 % of the variation with all variables significant at $P<0.001$. The most significant variables that controlled erosion were %*lit* which explained 48 % of the variation, %*veg* explained a further 31 % and %*crust* an extra 3 %. Based on this analysis, %*veg* and %*lit* were combined to form the variable %*veg+lit* and regressed against $ln\ Q$ (**Fig. 1**) to give a regression coefficient of $r^2=0.77$ which was significant at $P<0.001$. This regression was done using data from all land units and paddocks, and gave the following form;

$$ln\ Q = 6.08 - 0.083(\%veg+lit) \quad [1]$$

Using this relationship it is possible to determine an average cover level required to control erosion on the sandplain country west of Cobar. The author, based on experience with the wind tunnel, has used an "erosion control" level of $Q < 5$ g/m/s. Land managers should aim to keep under this level of erosion. This erosion level is less than would be noticed by land managers and most extension staff. A zero level of erosion has not been set as this is rarely achieved even under vigorous perennial pasture. Therefore, solving equation 1 with $Q = 5$ g/m/s gives a critical cover level (%*veg+lit*) of 54 %. Cover levels greater than 54 % will reduce the risk of erosion and ensure greater land stability.

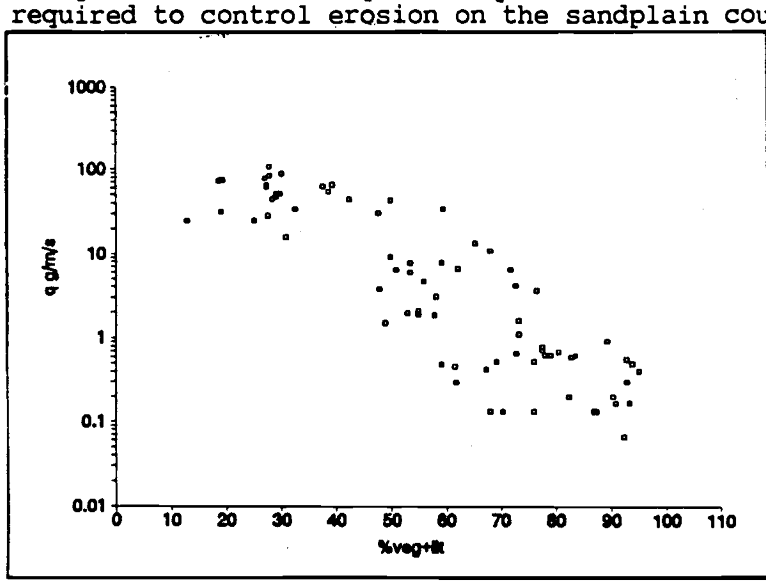

Figure 1: Relationship between soil flux (*ln q*) and vegetation cover (%*veg+lit*) for all sites assessed at "Lynwood".

Dry aggregation

Dry aggregation > 0.84 mm, as determined by dry sieving, was determined by Chepil (1950) as one of the most important factors affecting wind erosion. As dry aggregation levels increase, erosion levels fall. In this study, %*DA* only explained 22 % ($P<0.001$) of the variation in $ln\ Q$ as vegetation factors predominantly influenced erosion factors.

The sandhills in Blitz and Hgoat have similar *%DA* levels (46%-49%), but the sandhill in the Mgoat treatment (MH) is higher (58%)(**Table 1**). This is attributed to the different surface conditions. The Blitz and Hgoat treatments both had highly disturbed surfaces caused by the high stock numbers. In these paddocks the surface of the sandhills were covered with loose sand (1-3 cm deep), in contrast, MH was heavily crusted and had little loose material. The combination of lower stock numbers, the crust remaining intact and the extra root binding from the live woollybutt is probably the reason for the higher *%DA* in MH.

Soil crusts

Soil crusting appears to be a function of stability of the paddock. It is hypothesised that there are two types of crust. One is an older thicker crust with a large proportion of organic matter. The second is a newly formed compact crust formed by recent wind and water erosion processes. The first type is found in Mgoat where the crust has suffered less stock traffic and erosion processes have not been as active. The second crust type found in Blitz and Hgoat are a function of erosion processes. In these cases the stable crust was broken down (most probably by stock trampling and wind erosion) and has been replaced with a crusted layer that forms the boundary between the loose sandy lag material being blown around by the wind and the uneroded soil beneath. Both crusts have the affect of reducing erosion rates but each signifies a different stage in the paddocks stability.

Cost of replacing lost nutrients as fertiliser

Of the eight sites evaluated, two were used to evaluate the costs associated with replacing the wind blown nutrients as fertiliser. The nutrients in the soil are concentrated in the top layers (**Table 2**). Therefore, any erosion removes the most fertile part of the soil. Wind erosion is particularly efficient at winnowing the fines and nutrients out of the top soil and leaving behind the less fertile sand (Leys and Heinjus, 1991). This is evident at the BH site where the wind blown sediments have an enrichment ratio of 2:1. The erosion levels of HH were 9 times less than BH and as such the winnowing process was far less developed. Enrichment ratios for HH were 1:1. This implies that sites with greater erosion have greater nutrient losses. This is because a greater mass of soil is moved thereby increasing the nutrient laden dust production from the soil.

The relative costs of erosion between the two sites vary by 8.6 fold. From **Table 3**, BH is losing the equivalent of $0.69/ha/min of fertiliser and HH is losing $0.08/ha/min for a 12 m/s wind at 15 cm height. It must be remembered that these are plot data and therefore the costings are only relative. This plot data indicates the potential losses. Paddock scale data would return different results (most likely lower) because of the reduction effect trees and shrubs have on wind flow and erosion.

CONCLUSIONS

Stocking rates had a marked effect, on soil cover levels, soil crusts and wind erosion. The combination of percentage live vegetation cover and percentage litter cover (*%veg+lit*) explained the greatest variation ($r^2=0.77$ $P<0.001$) in soil erosion (*ln Q*). For all eight sites combined (sandhills, flats and sandplain), erosion control ($Q < 5$ g/m/s) was achieved with a *%veg+lit* level of > 54 %.

Higher stocking levels in the Blitz treatment reduced cover levels (*%veg+lit*) on the sandhills to low levels (26.5 %) with the only cover being scattered woollybutt grass butts and litter. On the flats, annual herbage litter increased cover to 50 %. In the Hgoat treatment, cover levels were higher than the Blitz with annual herbage litter giving good cover on open areas of 54 % and 80 % for the sandhill and sandplain respectively. Where there were red box trees, cover level fell to 58 % and 44 % for the sandhill and sandplain. In the Mgoat treatment, cover levels were considerably higher on the sandhill (86 %) and similar to the Hgoat on the open flats (81 %). The big difference was that the cover on the sandhill was predominantly live woollybutt with foliage averaging 20 cm in height.

Stocking rates also had a marked affect on the soil crusts. Observation indicates that the stable long term crust that was present in Mgoats was broken up by stock trampling and erosion processes in the Hgoat and especially in the Blitz treatments. The reduction in the crusts resulted in greater erosion rates.

Erosion rates (*ERO*) varied between treatments. By comparing the same land unit in each treatment (sandhill without trees) the impact of the different stocking rates is evident. The Mgoat was 0.3 % (*ERO* = 0.018 t/ha/min) and the Hgoat was 8.3 % (*ERO* = 0.561 t/ha/min) of the Blitz erosion rate of *ERO* = 6.78 t/ha/min.

Nutrient losses associated with the erosion were also substantial. The dust (eroded material < 75 µm in diameter) was considerably enriched and in the Blitz treatment contained twice the nutrient concentrations of total N, total P and percentage organic carbon than the 0-1 cm surface soil. In the Hgoat treatment, enrichment was not taking place because the nutrient concentrations of the eroded dust were the same as the soil. This was due to the erosion processes being contained by the crust and cover levels.

The simulated wind of 12 m/s measured at 15 cm above the ground in the wind tunnel is equivalent to a 75 km/hr wind measured at 10 m as reported by the Meteorological Bureau. If nutrients lost through wind erosion were to be replaced as fertiliser, it would cost $0.69/ha/min for the Blitz treatment, and $0.08/ha/min for the Hgoat treatment for a 75 km/hr wind.

Based on this research, the Blitz treatment has high soil and nutrient loss levels. In the long term these losses would result in major land degradation. The success of this treatment depends on the recovery of the pastures. This data is not available yet and as such recommendations on the viability of this treatment for controlling woody weeds can not be made. The Hgoat treatment had just enough cover (although it was primarily annual herbage) to control erosion and nutrient losses. It appears it would be possible to use this strategy to remove woody weeds with goats, provided cover levels could be maintained in the future at these stocking rates. The Mgoat treatment provides adequate cover and has very low erosion levels, however, removal of woody weeds is less effective at these stocking rates (Muir, 1991).

ACKNOWLEDGMENTS

The financial assistance of the Rural Credits Development Fund of the Reserve Bank for the construction of the wind tunnel and the National Soil Conservation Program for funding the research are acknowledged. The assistance and co-operation of Michael Case (Soil Conservation Service) and the staff from the Cobar offices of the NSW Department of Agriculture and the Soil Conservation Service with field work is much appreciated.

The author acknowledges the contribution of Alan Lynch and Kenn Tews (Griffith University) for the particle size and nutrient analysis.

REFERENCES

Bagnold, R.A. 1941. The physics of blown sand and desert dunes. Chapman and Hall. London.

Brock, D. 1875. To the desert with Sturt: a diary of the 1844 expedition. (Ed. K Peake-Jones). South Australian Historical Society. Adelaide.

Bruce, R.C. and Rayment, G.E., (undated). Analytical methods and interpretations used by the agricultural chemistry branch for soil and landuse surveys. *Queensland Department of Primary Industries*, Bul. QB82004.

Chepil, W.S., 1950. Properties of soil that influence wind erosion. I. The governing principle of surface roughness. *Soil Sci.* **69**:149-162.

Condon, R.W. 1976. History and administration of the Western Division. *Agric.*

Gaz. NSW. **87**:2-5.

Johns, C.G., Tongway, D.J. and Pickup, G. 1984. Land and Water Processes. *In* 'Management of Australia's Rangelands'. (Eds G.N. Harrington, A.D. Wilson, and M.D. Young). CSIRO, Melbourne. pp.25-40.

Leys, J.F. 1991. The effect of prostrate vegetation cover on wind erosion. *Vegetatio.* **91**:49-58.

Leys, J.F. and Heinjus, D.R. 1991. Simulated wind erosion in the South Australian Murray Mallee. Soil Conservation Service of N.S.W., Chatswood.

Leys J.F., and Raupach M.R. 1991. Soil flux measurements using a portable wind erosion tunnel. *Aust. J. Soil Res.*, **29**:233-52.

Marshall, J.K, 1972. Principles of soil erosion and its prevention. *In* 'The use of trees and shrubs un the dry country of Australia'. Department of National Development, Forestry and Timber Bureau. Australian Government Printing Service, Canberra.

McTainsh, G.H, Lynch, A.W. and Burgess, R.C. 1990. Wind erosion in eastern Australia. *Aust. J. Soil Res.* **28**:323-39.

Muir, S. 1991. Control of woody weeds. *Agnote Reg3/25*. NSW Agriculture and Fisheries, Dubbo.

Newman, J.C, and Condon, R.W. 1969. Land use and present condition. *In* 'Arid Lands of Australia' (Eds R.O. Slatyer and R.A. Perry). Australian University Press, Canberra.

Noble, J.C. and Tongway, D.J. 1986. Pastoral Settlement in Arid and semi-arid rangelands. *In* 'Australian Soils: The human impact'(Eds J.S. Russell and R.F. Isbell). University of Queensland Press, Brisbane.

Northcote, K.H. 1979. A factual key for the recognition of Australian soils. CSIRO. Rellim, Adelaide.

Page, A.L., Miller, R.H. and Keeney, B.R. 1982. Methods of soil analysis part II Chemical and microbiological properties. 2nd Edition American Society of Agronomy Inc., Soil Science Soc. of Am. Inc., Madison, Wisconsin, USA.

Ratcliff, F.N. 1935. Soil Drift in the arid pastoral areas of South Australia, Pamph. No. 64. *Council for Scientific Industrial Research,* Melbourne.

Raupach, M.R. & Leys, J.F. 1990. Aerodynamics of a portable wind erosion tunnel for measuring soil erodibility by wind. *Aust. J. Soil Res.*, **28**:177-91.

SAS Institute Inc. (1988). SAS/STAT™ User's Guide, Release 6.03 Edition. Cary, NC : SAS Institute Inc. 1028pp.

Semple, W.S., and Leys, J.F. 1987. The measurement of two factors affecting the soil's susceptibility to wind erosion in far south-west N.S.W. *Western Region Tech. Bul.* 28. Soil Conservation Service of NSW, Sydney.