Wind erosion: the winnowing of our soils

When the vivid-white snow on New Zealand's lofty peaks suddenly turns distinctly reddish — as it last did in December 1987 — you can't hide the fact that Australia experiences severe wind erosion. That tell-tale colour, a sprinkling of red dust, shows that another layer of our topsoil has just blown away.

Horizontal red bands in New Zealand's glaciers tell us how many times that eye-catching phenomenon has repeated itself. And oceanographers have found that, for thousands of kilometres to the east and west of our continent, the sea floor is covered with metres of kaolinitic clay, the same stuff that makes up the fine fraction of much of Australia's soil.

Ships far out in the Indian Ocean periodically report red clouds of Australian dust, and now and again Fijians notice a similar apparition. Sometimes traces even reach Antarctica.

In February 1983 a choking plume of dust — covering thousands of square kilometres — blanketed Melbourne, reducing visibility to less than 100 metres. That one storm is conservatively estimated to have stripped 250 000 tonnes of topsoil from north-western Victoria.

Visit the Mallee or Riverina and you will see wind-blown mounds up to 3 m high piled up by the side of the road. Like the New Zealand glaciers, these display bands recording each episode of soil loss.

Because of harsh climate, Australia has extremely fragile soil. For countless millennia, winds have winnowed the soil over much of the country, picking up the fine, fertile fraction and leaving behind heavy sand grains. Ages ago, under a kinder climate, the Red Centre had fertile and productive soils. Now, nearly all that remains is sand. The Australian 'continental dunefield' covers more than 3 million sq. km — some 40% of the country.

No amount of water, organic matter, or fertiliser will ever reverse the process and make that arid country highly productive again. It gives us an image of how more of the country — in particular the vulnerable semi-arid pastoral and cropping land — may end up if we aren't careful.

Whereas water is the most active agent of erosion on loams and clays, wind is the prime force on exposed sandy soils. When we clear the land for cultivation or overgraze it, the topsoil layer and its nutrients become exposed to these forces.

Studies have shown that the loss of 70 tonnes of topsoil per hectare can reduce grain yield by half. Yet that amount of soil corresponds to a layer only about 7 mm thick! Whereas water erosion tends to disfigure the land dramatically, wind can persistently blow away a millimetre or two every year without anybody noticing anything amiss.

Wind erosion is largely a problem of the semi-arid zone — an area covering some

500 000 sq. km — where light sandy soil combines with light vegetation cover (most of the arid zone has already been winnowed into sand dunes). Using conservative figures, soil scientists have estimated that 57 000 sq. km of grazing and cropping lands require protection from continuing wind erosion, and an equal area, suffering from the action of both wind and water, requires remedial action.

Most of the semi-arid pastoral lands in Australia have been grazed for little more than a century. During that period, they have suffered periods of overstocking and severe land degradation. In general, they receive better management today and are not being eroded as fast as they were.

However, for cultivated areas in the semi-arid zone, the situation is most perilous, says Dr Colin Chartres of the CSIRO Division of Soils. Farmers are clearing, and sowing to wheat, in New South Wales and Western Australia on land with an annual rainfall as low as 300–400 mm and in Queensland in areas with only slightly higher rainfall. Drought and strong wind may see this land blow away in the same spectacular way that soils in north-western Victoria did in February 1983.

The Victorian Mallee provides an object lesson. Last century, its sandy light soils were effectively stabilised by mallee eucalypts. When the land was taken up for wheat-farming early this century, the small size of the soldier settlement blocks and the lease conditions encouraged massive clearing.

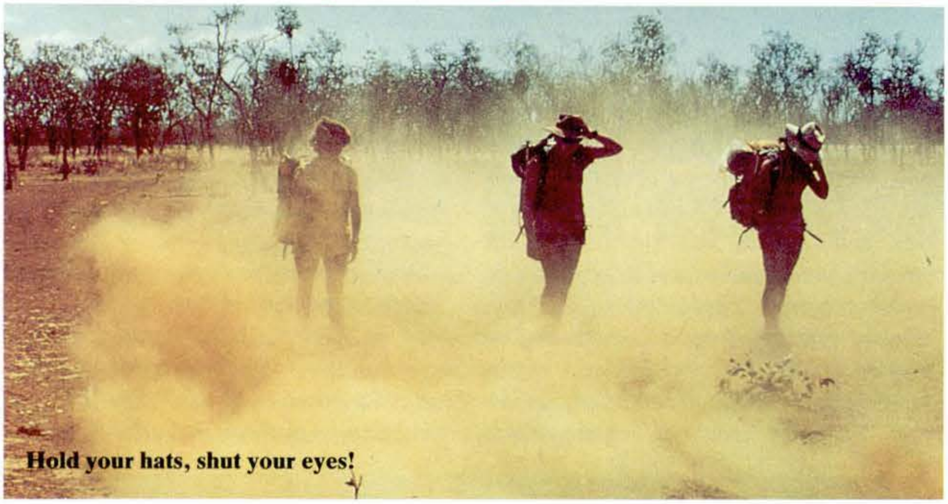
The soil was exposed to frequent tillage and to drying westerly winds, and wind erosion was chronic, reaching disastrous proportions during the 1930s drought. Soil became sand drifts, and tree roots were exposed and fences undermined. Eroded material blocked roads, railways, and water-supply channels, and dust storms turned midday to twilight.

Any land use that results in substantial erosion amounts effectively to 'mining the soil'. In Australia, the rate of soil formation from bedrock is generally so low that for practical purposes we can call it zero. The main replacement mechanism is the spreading of silt by flooding.

Research by Dr Pat Walker of the CSIRO Division of Soils, using radiocarbon dating, indicates that the formation of 1 mm of soil from alluvium in south-eastern Australia may, typically, take 20–30 years. Our soils are irreplaceable, says Dr Walker, and he warns that, in the long term, the cumulative loss of soil by erosion undermines the very viability of Australian agriculture.

Andrew Bell

Where the dust comes from, and goes

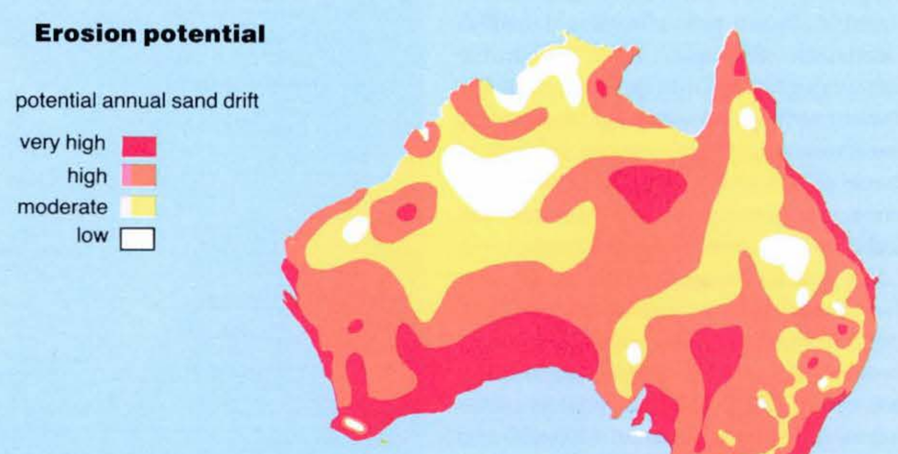


Hold your hats, shut your eyes!

If you want to know where the danger of wind erosion is greatest, the obvious starting point is a wind map of Australia. You need to take account of the fact that the amount of soil moved by the wind depends on the cube of the wind speed above a certain threshold velocity. And you need to know where bare soil is a prominent feature of the landscape, and the nature of the soil.

Dr Jetse Kalma, Mr Garry Speight, and Dr Bob Wasson, of the CSIRO Division of Water Resources, have drawn on at least 4 years' wind data from 732 Bureau of Meteorology weather stations to map wind-erosion potential. They used the 3 p.m. wind-speed readings and took the threshold velocity for wind erosion to be 6·5 m per sec. (at the recording height of 10 m). They assumed flat, dry, sandy soil with grains 0·25 mm in diameter — a specification that broadly covers nearly all the arid-zone dunefields, parts of the Mallee, Wimmera, western New South Wales, and southern Western Australia, and most coastal dunes.

The researchers produced a series of maps detailing wind-erosion potential in different parts of the year and averaged over the year. Some of their findings, including a generally close correlation between the average direction of sand-shifting winds and the orientation of dunefields across the country, are illustrated below and on page 6. Intriguingly, the eye of the entire whorl of dunes is none other than Australia's monumental monolith, Uluru.



This map shows erosion potential based on wind speeds. The actual erodibility of the soil also needs to be taken into account in assessing wind-erosion risk.

Where there's dust, there's (been) soil

Needless to say, situations where the wind picks up sand grains and moves them along a bit differ greatly from those where it winnows sandy soil into sand and dust. The

Fortuitous fertility

If the erosion cloud has a silver lining, it comes in the shape of wind-blown deposits, also known as aeolian accessions or parna (the Aboriginal word for dusty ground).

Dr Colin Chartres, Dr Pat Walker, and Mr John Hutka, of the CSIRO Division of Soils, and Dr Allan Chivas of the Australian National University have established that — during particularly arid phases that occurred in the past 2 million years — fine sands, silts, and clays were blown in an easterly direction from the riverine plains of western New South Wales and deposited on higher land to the east.

These are important to agriculture on the slopes and tablelands, amounting to Nature's version of aerial crop-dusting. The wind-blown deposits contain not only fine clays that improve soil structure, but also essential nutrients and trace elements.

That's the good news, but of course these fine materials remain highly prone to wind erosion and, as we have seen, their next stop is the Pacific Ocean if soil management is inadequate.

To determine whether aeolian accession had occurred in higher-rainfall areas of New South Wales, Dr Chartres and his colleagues applied two forensic-like techniques — particle-size and oxygen-isotope analyses — to soil samples from sites near Harden, Sutton, and Bemboka.

They found that the ratio of two oxygen isotopes in quartz from parna differed distinctly from that in samples of soil derived from underlying rocks due to weathering. Such isotope analysis, together with informative peaks and discontinuities in particle-size distributions, convinced the scientists that wind-blown material from the western plains had indeed been added to the red podzolic soils they examined.

In fact, at Lynwood (a farm near Harden on the Southern Tablelands), which had the greatest amount of aeolian material added, it seems that the addition and incorporation of wind-blown clay, over thousands of years, has led to the development of a well-structured red earth soil rather than a red podzolic, with its difficult-to-manage sand-on-clay profile. Many wheat-farmers on red earth soils in south-eastern Australia should be thankful for the phenomenon of aeolian accession!

On the other hand, parna causes real headaches for exploration geologists. Mining companies in search of mineral deposits often use airborne and ground-based mapping techniques, including radiometric methods, to pinpoint promising areas. The trouble is that exotic dust deposited on the ground by wind contaminates the signatures picked up by the sophisticated radiometric equipment, making it much more difficult to locate good mineral deposits.

Together with Dr Chartres, Dr Bruce Dickson and Mr Keith Scott, both of the CSIRO Division of Exploration Geoscience, are attempting to find a way around this problem by analysing the concentration and distribution of natural radioisotopes (including uranium, thorium, and potassium) in aeolian deposits so that they can correct for this dilution effect on radiometric signatures.

Steve Davidson

The effect of aeolian accessions on soil development on granitic rock in south-eastern Australia. I–III. *Australian Journal of Soil Research*, 1988, **26**, 1–53.

dust, harbouring valuable nutrients and organic matter, is likely to be carried far away.

Therefore, to gain most value from a wind-erosion map, you really need to read it in conjunction with a soil-erodibility map, which takes into account such things as soil type, surface roughness, and moisture content — a difficult exercise and one that hasn't been attempted on a large scale yet.

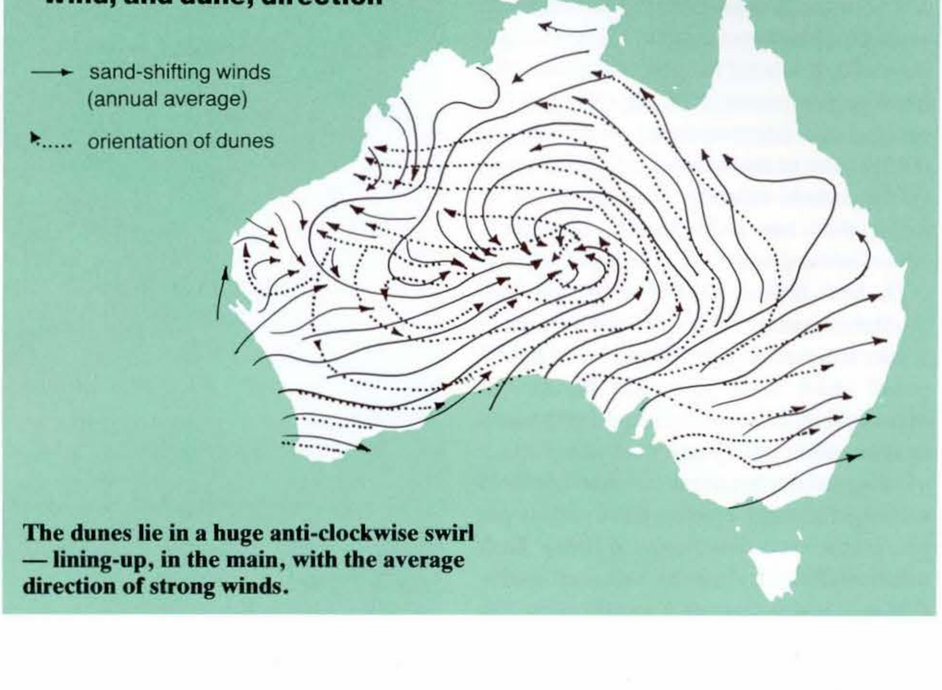
However, another approach does provide useful information. This involves locating where dust has been flying loose. Dr Grant McTainsh and colleagues at Griffith University, Brisbane, have taken the meteorological records for more than 150 stations throughout Australia and plotted the frequency of dust storms at each of them. (The weather bureau defines a dust storm as an event when locally raised dust reduces visibility to less than 1 km.)

The resulting map, reproduced on page 7, shows that the regions of greatest dust-storm frequencies in the period 1960–84 are in central Australia and the central Western Australian coast. More dust storms occurred in the semi-arid region (200–400 mm annual rainfall) than in arid regions (less than 200 mm) — an observation in harmony with the idea that the former still has fine particles left to lose, whereas the arid zone comprises mostly sand and little else.

In another recent exercise, Dr McTainsh compared the prevalence of dust storms at stations in semi-arid regions of Queensland, New South Wales, and Victoria with the numbers you would expect to get based on the two major factors controlling wind erosion — wind speed and soil moisture (expressed as the difference between annual rainfall and potential evaporation). In this way, he could pick out regions where agricultural activities or high local soil erodibility appeared to be adding accelerated wind erosion to the natural background process.

Four regions showed up as suffering excessive numbers of dust storms (see the map on page 9). Not surprisingly, these included the Mallee–Riverina region — long recognised as having the most serious wind-erosion problem in Australia.

Wind, and dune, direction



The dunes lie in a huge anti-clockwise swirl — lining-up, in the main, with the average direction of strong winds.

Of the three other areas pinpointed, all in Queensland, one — centred on Charleville — has erodible sandy red earths. The others, surrounding Longreach and Urandangie, occur in the Channel Country, which has cracking clay soil.

Normally, the cracking clays resist wind erosion, but Dr McTainsh believes the dust raised here comes from alluvium spread by the Cooper and Diamantina Rivers. The Channel Country is rich in this water-deposited fine silt and clay. A huge dust storm there in December 1987 was, Dr McTainsh postulates, the source of the red dust that landed on New Zealand a few days later.

Where does it come from?

In fact, he considers silt left behind by floods is the principal source of the dust whipped up by the wind. As noted earlier, the massive sand dunes of the arid zone are ancient remains of soil picked clean by the wind, and dust storms are a phenomenon largely of the desert margin where the wind still has something to pick at.

Dr McTainsh believes that erodible soil remains in the semi-arid zone not because vegetation has protected it for thousands of years but because rivers run themselves out there from time to time and dump their sediment. In other words, our erosion-prone soils are often river floodplains, and the soils are recent (geologically speaking).

The key to the process is the topography, which incorporates two vast internally draining river basins — the Lake Eyre and Murray–Darling Basins. Rivers in these basins arise in well-watered parts of the Great Dividing Range, and wash down sediment to their much drier lower reaches.

Lake Eyre, of course, is self-contained. As for the Murray–Darling Basin, very little sediment escapes to the mouth of the Murray, surprising though that seems, since the river's tributaries flow through country with very low gradients — 10 cm per km, more or less. Most of the sediment settles out when the rivers slow down in the semi-arid middle reaches of Queensland, New South Wales, and Victoria.

Our map of dust-storm centres shows that areas highest in dust-storm frequency lie close to river floodplains. For example, the Mallee–Riverina zone extends up the floodplains of the Darling and Murrumbidgee Rivers.

When the Darling floods onto the flat dry plains of New South Wales, it divides into a complex network of channels called anabranches. Fine sediment will accumulate in the anabranches or, if the water gets that far, in the Menindee Lakes. Between Bourke and Wilcannia — upstream of the Menindee Lakes — hydrologists estimate that more than one-quarter of the total river flow is overbank flow.

The two basins tend to contribute different types of dust. The Channel Country rivers supply largely kaolinitic clays, whereas the Murray–Darling system brings a more varied array of minerals.

Dr McTainsh considers that dust monitoring has an important role to play in keeping an eye on wind-erosion activity. He has set up high-volume air samplers to collect dust at Buronga, Fowlers Gap, and Gunnedah, N.S.W., and at Charleville, Qld. In addition, the quality of the meteorological record and the number of weather stations recording dust should be increased, he thinks. Remote sensing, too, may be able to provide a fuller picture of dust in the air.

Andrew Bell

More about the topic

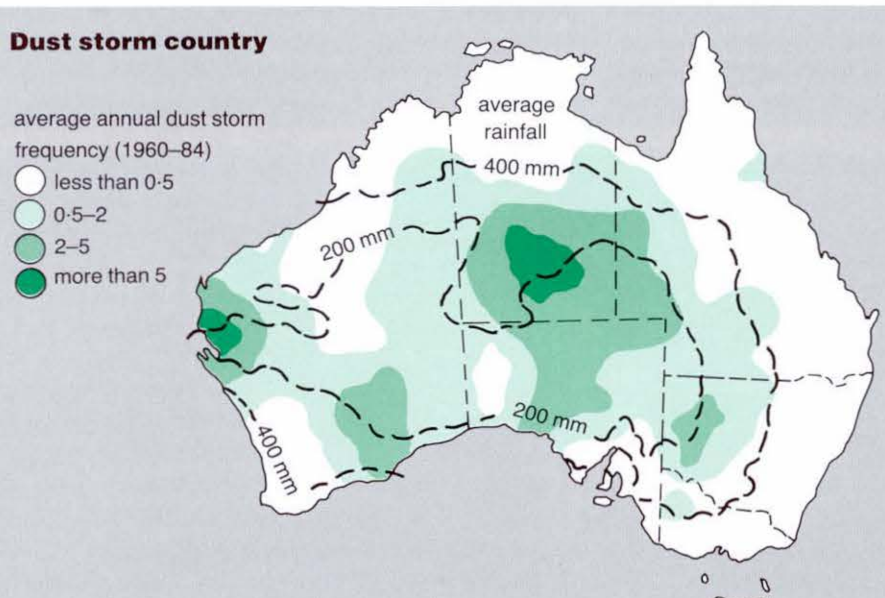
Potential wind erosion in Australia: a continental perspective. J.D. Kalma, J.G. Speight, and R.J. Wasson. *Journal of Climatology*, 1988, **8**, 411–28.

Wind erosion in eastern Australia. G.H. McTainsh, A.W. Lynch, and R.C. Burgess. *Australian Journal of Soil Research*, 1990, **28**, 323–39.

Aridity, drought and dust storms in Australia (1960–84). G.H. McTainsh, R. Burgess, and J.R. Pitblado. *Journal of Arid Environments*, 1989, **16**, 11–22.

Conserving soil in mallee country

The Mallee, in north-western Victoria and south-western New South Wales, has a long history of serious wind erosion. Synonymous with multi-stemmed eucalypts and wheat, the area also suffers frequent bad dust storms.



Strong winds and erodible soils; dust storms require both.

The problem isn't as serious now as during the drought years of the 1930s and '40s, when sand drifts closed roads, but continued erosion represents a further loss of irreplaceable topsoil.

To counter the ill effects of 70 years of clearing and farming in the mallee country of New South Wales, that State's Soil Conservation Service has been ascertaining the relative erodibilities of soils in the region to determine land capability and has developed a range of tillage systems that minimise wind erosion in cereal crops.

Fortunately, most landholders no longer cling to the view that 'the better she blows, the better she grows' and adoption of conservation measures like stubble retention is now the norm in south-eastern New South Wales, north-western Victoria, and parts of South Australia.

Recently, Mr John Leys of the Soil Conservation Service and Dr Mike Raupach of the CSIRO Centre for Environmental Mechanics developed a portable wind tunnel for measuring wind erodibility of soils. This allows them to assess the effectiveness of various farming systems in controlling erosion — and to objectively determine

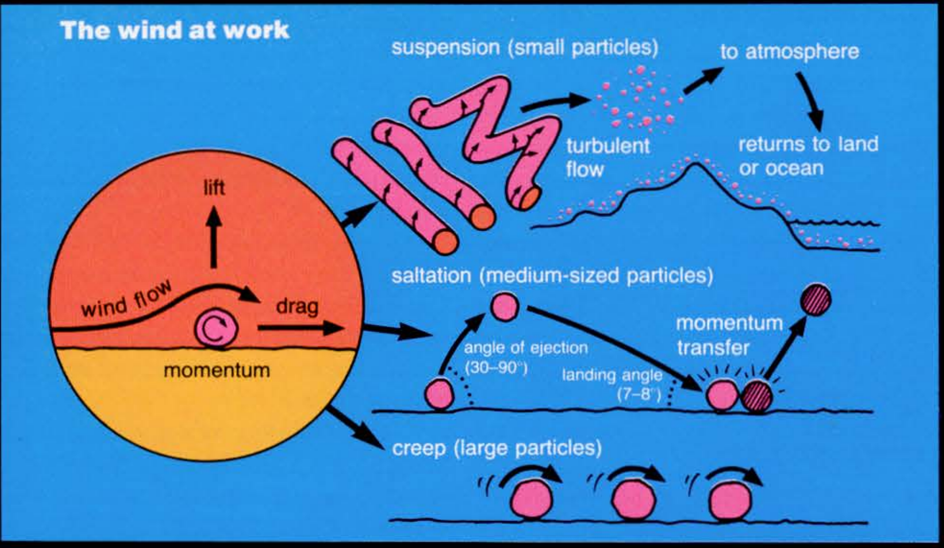
The physics of wind erosion

To understand what's going on when wind raises dust from the soil surface, we need to know a bit of fluid mechanics.

First, average wind speed above level uniform ground increases rapidly with height close to the ground and much more slowly further up. This happens because the ground exerts a drag on the wind, and so (on average) momentum flows down towards the ground. This momentum flux is what actually drives wind erosion, since soil grains are set in motion by the transfer of momentum to them from the flowing air. Mathematical equations can be used to quantify such erosion processes and to help us decide what to do about them.

Wind moves soil particles in three ways, according to whether they are small, medium, or large (see the diagram).

- ▷ Small particles such as clay and silt (with diameters less than 50 micrometres) go into suspension in the air. Once airborne they are buffeted by both wind and turbulent fluctuations, so the particle motion is erratic and turbulent, like that of smoke. Suspension of small soil particles, which include a large part of the soil nutrients and organic matter, is the first form of erosion to occur on windy days; soil mixing is required before further losses occur.
- ▷ Medium-size soil particles, the fine sands (with diameters between 50 μm and 1 mm), undergo erosion by 'saltation' — the typical hopping motion of wind-blown sand across the ground. Grains are ejected violently upwards from the surface at a steep angle, due to either forces of the wind or the impact of other flying grains. After reaching heights of up to 10 cm or so, they fall back to the ground at a shallower angle and with greater horizontal speed, so the saltating grains transfer a lot of momentum from the air to the soil. This usually leads to an avalanche of saltation as more and more particles are ejected only to return and bombard the surface.
- ▷ Large particles, the coarse sands and gravels exceeding 1 mm, move by creep. They roll sluggishly across the surface, but never leave it.



Wind can move soil particles in three different ways, according to their size.

The three kinds of particle motion carry material different distances. Suspension causes fine particles to diffuse upwards from the surface to great heights. Hence, the suspended fine fraction can be transported kilometres or thousands of kilometres. Saltation can shift large volumes of sand from tens of metres to a few kilometres in just a single wind storm and is primarily responsible for sand-dune movement, piling of sand against fences, drift across roads, and so on. Creep moves particles just a few metres.

The minimum wind speed needed to initiate erosion is known as the threshold friction velocity.

Clay particles, organic matter, and soil aggregates are seldom spherical like sand grains. Individual clay particles are usually plate-like, while fragments of organic matter are often fibrous.

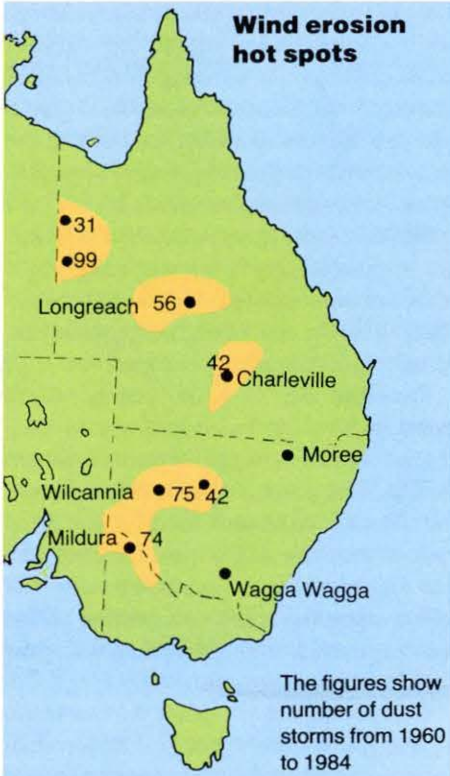
Because aerodynamic forces on these non-spherical particles are greater, the threshold friction velocity is likely to be lower than for sand. This means that many agricultural soils containing fine clay or organic particles in non-aggregated form, such as a loam soil after ploughing, will, if dry, erode at lower wind speeds than sand. Mr Leys' field observations confirm that these fine particles, so important to agricultural production, are indeed removed in very light winds.

Steve Davidson

land capability. The tunnel, which is transported on a trailer, is about 9 m long and sits on the ground surface. A fan provides a controlled artificial wind that flows across the soil in the field and the operator collects and weighs any wind-blown material that is caught in dust traps within the tunnel.

The researchers can accurately vary the wind speed in the tunnel and have refined its original design to ensure that it reproduces as closely as possible the aerodynamic properties of the turbulent winds in the atmospheric surface layer that actually

The portable wind tunnel helps assess soil erodibility.



Erosion hot spots in eastern Australia — regions that experience significantly more dust storms than you would expect — identified by Dr McTainsh. They include the Mallee–Riverina region.

***Left:* Undisturbed and cleared dunes in the Mallee — the cleared area ravaged by wind erosion.**

Retaining 2 tonnes of stubble per hectare provides good protection against wind erosion on sandy loam soils.

cause erosion. Mr Leys has used the wind tunnel to test the erodibility of eight predominantly aeolian (wind-blown) soil types in south-western New South Wales that range in surface texture from sand to clay.

Cultivation, aggregation, and erosion

His results show that sands have erosion rates about a hundred times greater than those for clays, with sandy loam soils being intermediate between the highly erodible sands and the more stable loams and clays. 'Dry aggregation' of the soils (measured as the proportion of particles exceeding 0·85 mm, determined by sieving) has a marked effect on the degree of erosion. Dry aggregation levels greater than 35% considerably reduce soil flux (mass of soil crossing a 1-metre-wide line per unit time), while aggregation greater than 60% reduces erosion to negligible proportions.

Comparisons between cultivated and uncultivated soils showed that cultivation increases wind-tunnel erosion rates for all soil types except the highly aggregated clay (which is not erodible anyway). Unfortunately, just one cultivation reduces dry aggregation of sandy soils to a very low level, with further cultivation resulting in a negligible decline. This highlights the advantages of a no-till system.

Cultivation also roughens the ground surface. This slows down the wind near the soil surface, which we would expect to reduce soil flux, but it also increases the drag on the surface soil. Wind-tunnel data showed that the greater surface roughness caused by cultivation does not reduce soil erosion, because the roughened material is also erodible. In fact erosion increases.

Dryland agriculture in the far south-west of New South Wales is limited to extensive grazing and cropping. On the basis of his wind-erodibility studies, Mr Leys has classified the landform/vegetation types in the region, according to their land-use capability.

Legislation requires that landholders with grazing leases who wish to clear or cultivate must obtain a cultivation permit or a clearing licence. The issue of these is subject to advice from the Soil Conservation Service. Wind-tunnel studies now allow the Service to make a more objective assessment of land capability and provide information on farming methods that control wind erosion and maximise yield.

Fluid mechanics for erosion control

Two basic methods involving vegetation exist for controlling erosion in cropping or grazing land. Increasing the surface cover is one; the other involves providing a windbreak in the form of a tree line or a strip-cropping system.

Taking stubble retention as an example, theory tells us that in a paddock with firmly anchored stubble, momentum transferred from the wind can be either harmlessly absorbed by the stalks or absorbed by the underlying soil — where it can cause erosion. The greater the density of stalks, the smaller the momentum transfer to the soil becomes, and the less the risk of erosion.

Data from wind-tunnel experiments, using artificial roughness, indicate that standing stubble provides almost complete protection of the underlying surface at densities exceeding 0·02 (where density is the frontal area of the stalks, as seen from the wind direction, per unit ground area). This converts to about 20 stalks per sq. m or a stubble cover of 0·6 tonne per hectare, in good agreement with the agronomic estimates.

By contrast, the practice of ploughing wind ridges to control erosion is not sound. Unlike standing stubble, here the roughness elements (the soil ridges) often consist of mobile material, especially on sandy soils. The problem is that, although the soil between them may be temporarily protected, the ridges themselves will absorb a lot of the momentum transferred from the wind and, being mobile, are subject to erosion. To make matters worse, soil particles from the ridges, bombarding the intervening soil, may initiate an avalanche of erosion.

Steve Davidson

More about the topic

Aspects of the physics of soil erosion by wind. M.R. Raupach. *Wind Erosion Research Update, Mildura*, 1987.

Blow or grow? A soil conservationist's view of cropping mallee soils. J.F. Leys. *Proceedings, National Mallee Conference, Adelaide*, 1989.