Saltation sand traps for the measurement of aeolian transport into the foredunes

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Abstract

An omnidirectional vertical sand trap is described for use in the measurement of sand transported by wind in the dune environment. In the field these traps yielded good results. The traps were calibrated by comparing them with a Bagnold trap of known efficiency and by wind tunnel experiments. Efficiency of the trap was not constant, being dependent on the wind speed, the grain-size distribution of the sediment and the moisture content. The calibration resulted an efficiency of between 15 and 20%. The highest efficiencies were observed for wind speeds of 8 m/s. For lower wind speeds the efficiency decreased because of the increasing importance of creep. With higher wind speeds the efficiency was reduced because of an increasing loss by blowout.

Keywords: Sand traps; Catching efficiency; Aeolian sand transport; Field measurements; Wind tunnel; Foredunes

1. Introduction

During a study of the aeolian sediment budget of the Dutch foredunes (Arens, 1992) measurements of aeolian sand transport were conducted in the field. The main purpose of the measurements was to gain insight into the aeolian transport process and its relationship with the environment. Sand fluxes were measured at several locations along a cross-section perpendicular to the foredunes. In order to collect and measure these fluxes, sand traps based on the idea of the "De Ploey's cake pan collector" (De Ploey, 1980) were constructed. In this paper the sand traps are described. Calibration results are presented together with some field data.

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2. Criteria for sand traps used in the dune environment

From several visits to beach and foredunes it was clear that the aeolian transport process on the beach differs from that on the foredunes. On beaches the sand cloud is limited to the lowest 0.25 m above the surface. The decrease of sand content with height is exponential. The aeolian transport process on a beach can be simulated in a boundary layer wind tunnel (e.g. Rasmussen and Mikkelsen, 1988). However, when the sand cloud moves over the foredunes, this relationship between sand concentration and height vanishes. The cloud is caught in a jet-like flow and, depending on topography, may reach a height of several metres, and be transported over several tens of metres (Arens et al., in press). This process is much more difficult to simulate in wind tunnels.

One important criterion for traps that are used in the field is that they should be omnidirectional. Unlike the controlled flow in a wind tunnel, the wind direction in the field is not constant with time. Variation in wind direction of some tens of degrees within tens of minutes is not uncommon. Continuous manual redirection of the trap is difficult to achieve. A trap which is open all round is the most convenient design for use at several locations where transport is being measured simultaneously.

The difference in transport mechanism between beach and foredunes makes it necessary that the height of the trap is variable. It is preferable to use identical types of traps on the beach and in the dunes. Measurements will be easier to interpret if there is no significant difference in trap efficiency, or in the effect that the design of the trap will have on the air flow. If the traps are adjustable their height can be adapted to the location (beach, low traps; foredune, higher traps).

In order to investigate the relationship between height and sand content (a reflection of the transport mechanism), the traps should be divided vertically into several compartments. Samples trapped at different heights can be compared to provide insight into the changes in grain populations during transport.

When gradients in transport rates are studied, several traps are needed that can be used simultaneously. If installation of the traps is easy, it is possible to respond quickly to changing conditions.

Many traps have been described in the literature (cf. Pye and Tsoar, 1990). However, most of them do not satisfy all the requirements mentioned above. A horizontal trap like the ones used by Bagnold (1954) or Horikawa and Shen (1960) does not cause disturbance of flow. However, a disadvantage is that its efficiency is not constant when the wind direction varies during the experiment. The use of several horizontal traps in a cross-section would be very time consuming and cause serious disturbances of the surface. Vane-traps which rotate to face into the wind (Fryberger et al., 1984) are difficult to construct and install and are therefore not suitable if many traps are needed. The traps described by Leatherman (1978) and Rosen (1978) are useful for measuring total transport and are easy to construct and cheap, but they do not give an indication of the height distribution of the transported sand. Traps described by Jensen et al. (1984) and Rasmussen and Mikkelsen (1988) are very efficient but mainly suitable for short-term (a period of a few minutes) experiments on the beach or in wind tunnels.

In 1980 De Ploey described a type of trap used for measuring aeolian transport on a dune near Kalmthout, Belgium. These traps consisting of stacks of cake pans, were omnidirec-

tional, vertical and easy to adjust in height. However, their main disadvantage was a low efficiency which was estimated to be less than 10%. Efficiency of the traps could be improved if the shape of the cake pans was modified. Two types of traps based on De Ploey's design, used for measurements on the beach, were developed by the Agricultural University of Wageningen. The first type consisted of stacks of soup cups, the second of stacks of coffee cups. Dimensions of the traps were small and efficiency was about 5 to 10% (van Dijk and Hollemans, pers. commun., 1991). The maximum height was approximately 0.40 m. Therefore these traps are not suitable for use in the foredunes.

3. Construction and calibration

A new pan (hereafter called a tray) consisting of a catching part and a storage compartment was developed (Fig. 1). It was believed that the shape of the tray compared with that of the original device would diminish the interference with the air flow and improve catching efficiency. Sand traps were constructed by stacking trays with a vertical distance of 0.05 m between each tray. On the beach, traps of six trays (0.25 m) were used; in the dunes traps of up to 31 trays (1.50 m), depending on wind speed and direction, were used. Traps of 1.50 m height appeared to be too low under conditions of strong landward aeolian transport. The height of the trap could have been extended, but then emptying and installing becomes very time consuming. In order to get a smooth transition between the trap and the surface, square boards of plywood were placed beneath the traps.
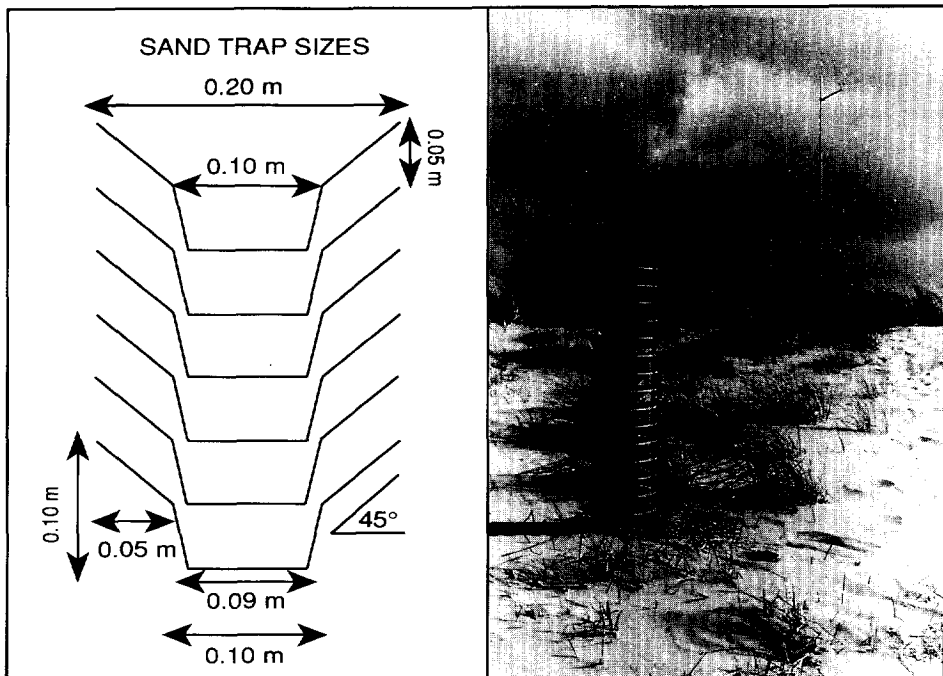

Fig. 1. Sand trap.

After several months of field measurements it appeared that the sand traps worked well. During many days with aeolian transport, fluxes were measured on the beach and from the beach into the foredunes. However, to calculate absolute fluxes and to compare predictions of potential transport from transport equations, the traps needed to be calibrated.

In the field some combined experiments with sand traps and horizontal Bagnold traps were performed. An experiment was carried out on the beach during conditions of strong wind (11 m/s at 5 m height). The beach surface was moist and therefore no creep occurred; all grains were transported in saltation. Comparison of amounts caught in the sand traps to the amount trapped by the Bagnold trap (with an efficiency of 139%, Al-Khalaf, 1986), rendered an efficiency, η_s, of 27%. Two more experiments were performed near the dune-foot, during moderate wind (7 m/s) under dry conditions. Transported sand moved within a thin layer and the amount of creep was considerable. For these experiments trap efficiency ranged between 7 and 13%.

Some important conclusions can be deduced from these experiments. It is obvious that the efficiency of the traps is not constant and is dependent on conditions. The efficiency increases with moisture content of the sediment. Moist grains are sticky and are therefore both difficult to entrain and easy to catch. It is important to note the decrease in efficiency when creep becomes more evident. The lowest tray is always a little above the surface. Creeping grains will encounter the side of the tray and move around the trap. If the lowest tray is positioned level with the surface, changes in the surface elevation during transport of sand will cause new problems.

The influence of several variables on catching efficiency was studied in the wind tunnel of the Institute of Soil Fertility, Haren, The Netherlands. A description of the wind tunnel is given by Knottnerus (1979). Effects of blowout on catching efficiencies were also studied. Wind speeds in the wind tunnel were measured at a height of 0.40 m above the tunnel floor, using a cup-anemometer. It appeared from measurements that the wind speed between 0.10 and 0.55 m was constant.

3.1. Scale models

At the start of the experiments, it was not clear whether the ratio between tunnel and trap dimension was too small. If so, the air flow would be influenced and results of the experiments would be less reliable. For this reason the experiments described above were also performed using scale models of the sand trap, with scales of 1:2, 1:2.5 and 1:3.

3.2. Loss by blowout

Traps filled with a certain amount of sand were placed in the wind tunnel and subjected to a range of wind speeds (6, 8, 10 and 13 m/s at 0.40 m height). After 10 min the amount of remaining sand was weighed.

3.3. Catching efficiency

About 5 m in front of the trap, a known amount of sand was supplied to the air flow from the roof of the wind tunnel (Fig. 2). Care was taken to avoid deposition in front of the trap,
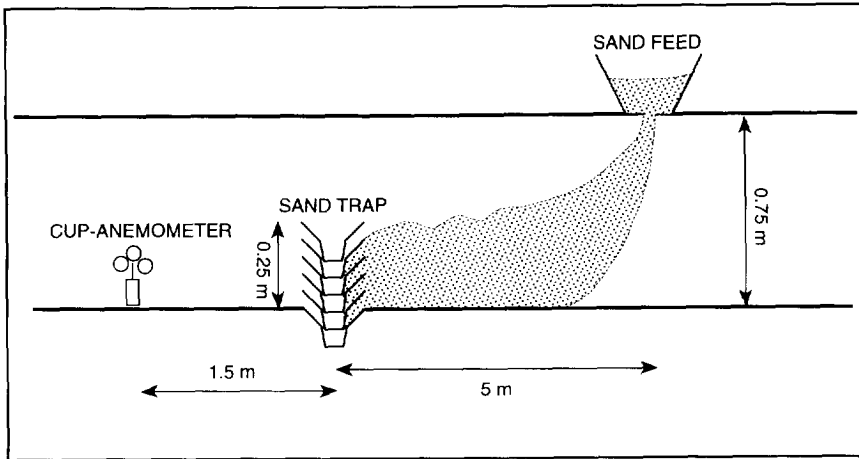
Fig. 2. Set-up of wind tunnel experiments.

so that at low wind speed (6 m/s) sand was supplied at a correspondingly low rate. The amount of sand that passes the sand trap equals the amount of sand supplied only if no deposition occurs. When all the sand had passed the trap, the contents of all trays were weighed. From the total amount of sand trapped the efficiency was calculated by:

$$\eta_s = \frac{\text{amount caught}}{\text{input}} * \frac{\text{tunnel width}}{\text{effective trap width}} * 100 \tag{1}$$

3.4. Comparison with isokinetic trap

In the wind tunnel of the Department of Earth Sciences, Århus University, some comparisons were made between the scale model 1:2.5 and an isokinetic trap. Interference of the isokinetic trap with the air flow is minimal, because air is sucked into the particle sampling tubes at the same speed as that of the undisturbed flow. The tubes pierce through the bottom of the tunnel floor and are connected to a vacuum cleaner. Flow through the tubes can be adjusted to an accuracy of about 0.15 m/s. Efficiency of the isokinetic trap can therefore be assumed to be close to 100%. For a detailed description of this trap and of the Århus wind tunnel, reference is made to Rasmussen and Mikkelsen (1988). Experiments were performed at three wind speeds. For each wind speed an experiment was repeated four times, twice with the isokinetic trap and twice with the scale model. After each of the four repetitions sand caught in the collector at the end of the tunnel was weighed to check that equal amounts of sand had been transported. Sand traps were placed in a sand bed, with the surface of the bed and the edge of the trap at the same height. After some minutes of exposure to a certain wind speed, the amount of transported sand was determined, and trap efficiency was calculated by comparing the amounts trapped by both the isokinetic trap and the scale model.
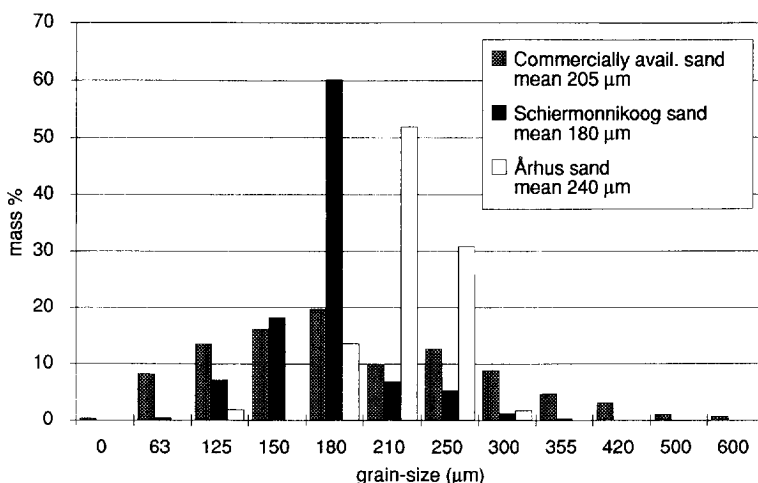
Fig. 3. Grain-size distribution of three types of sand used in efficiency experiments.

3.5. Grain-size

Most of the calibration experiments were performed with sand collected at the beach of Schiermonnikoog. To investigate the influence of grain-size, some experiments were repeated, using a slightly coarser, less well-sorted, commercially available sand. The sand used for the comparison with the isokinetic trap was coarser than the sands used in the wind tunnel in Haren (mean grain size 240 μm). The grain-size distributions of the three sands are displayed in Fig. 3.

4. Results

4.1. Loss by blowout

During high wind velocities and low sand feed considerable amounts of (already trapped) sand are blown out. The effect is reduced when sediment grain-size increases (Table 1). Loss by blowout on average is less evident in the lowest tray because of low wind speeds near the surface. This implies that efficiency of the trap is not constant with height and that the maximum efficiency is found in the lowest tray. Fig. 4 presents the average loss by blowout observed at different wind velocities, for two sands. At low wind speeds, up to 8 m/s, the effect of blowout is limited. However, at higher wind speeds most of the sand is lost. At 13 m/s (corresponding to a wind speed of about 20 m/s at 5 m height) more than 98% of the Schiermonnikoog sand disappears and approximately 70% of the slightly coarser, less well-sorted sand. The amount of blowout changes per trap. Because of the construction technique used, the trays are not identical. The result is that the distance between trays varies slightly (in the order of mm's), which affects the blowout process. Sediment curves for different size classes (Fig. 5) indicate that fine grains are not preferentially blown out. It is

Table 1
Percentage of sand left per tray (weight) after blowout experiment (trap D)

Height (cm)	Wind speed (m/s at 0.4 m)							
	5	7	8		10		13	
			a[a]	b[a]	a	b	a	b
2.5	100.0	99.9	99.2	96.8	65.2	81.8	0.1	47.2
7.5	100.0	96.4	84.0	100.0	38.9	92.6	0.4	17.6
12.5	100.0	100.0	98.3	100.0	82.1	94.6	1.7	19.3
17.5	100.0	94.5	84.4	99.8	11.4	100.0	0.1	74.4
22.5	100.0	93.6	82.9	95.7	20.9	61.9	0.3	2.5

[a]a, Schiermonnikoog sand (180 μm); b, Commercially available sand (205 μm).

therefore assumed that the grain-size distribution of the trapped sand is not influenced by the trap itself.

4.2. Catching efficiencies

Averaged sediment curves (Fig. 6) clearly show an exponential decrease of sand collected with height. In the case of low wind speeds the decrease is more pronounced than in the case of high wind speeds. For higher wind speeds the effects of blowout are obvious as the curves become irregular. More than 90% of the efficiency is determined by the sand content of the lowest tray. The overall effect of blowout on efficiency is less than expected on the basis of Fig. 4. Probably loss by blowout is smaller than during the blowout experiments because of the sand feed. However, blowout reduces the possibility of an accurate description of the sediment curve. The expected linearity of the curve is disturbed.

Fig. 7 shows the efficiencies for three traps calculated for all experiments with the average efficiency of each trap in relation to wind speed. Note that scatter is very high in the range between 7 and 9 m/s. This is possibly related to the rate of sand supply, which is rather critical in this range of wind speeds, but a satisfactory explanation cannot yet be given. The
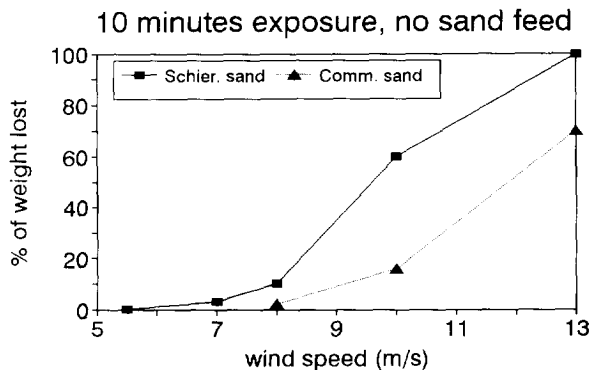

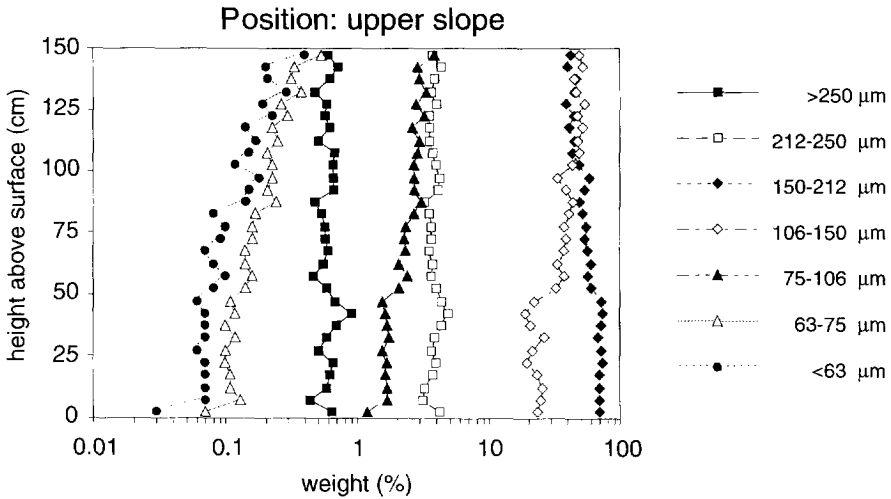Fig. 4. Average loss by blowout for several wind velocities and sands.

Fig. 5. Sediment curves for all grain-size fractions.

differences in average efficiency for wind speeds 6, 8, 10 and 13 m/s are statistically significant (van Blom and Ditvoorst, pers. commun., 1993). For 6 and 8 m/s the efficiencies of different traps do not differ significantly. However, for wind speed 13 m/s the differences are statistically significant, probably due to the variation in blowout for different traps.

For all scale models the effective catching surface has been calculated, as the product of the effective width (10 cm for the 1:1 model) and height between successive trays. The amount of trapped sand is divided by the effective catching surface and the supplied amount in order directly to compare sediment curves of different scale models. Fig. 8 shows that at several wind speeds sediment curves of all scale models are comparable, as are the derived efficiencies (Fig. 9). This implies that the size of the models did not affect the results and that the size of the 1:1 model was not too large for the wind tunnel.
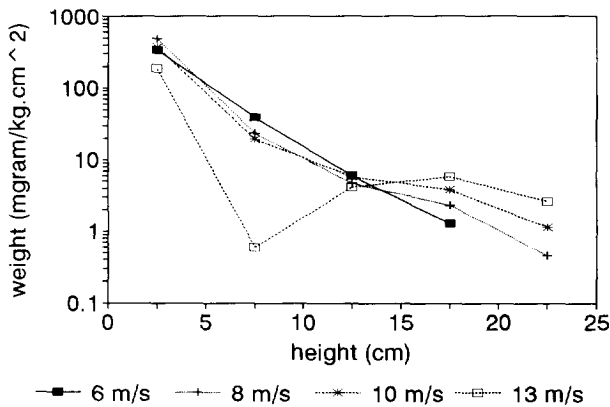
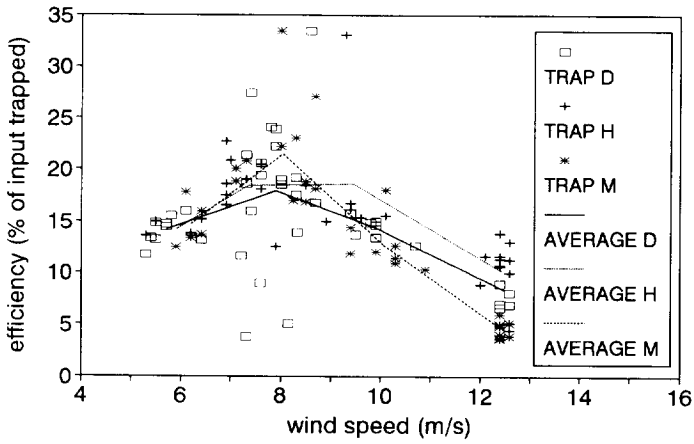Fig. 6. Averaged sediment curves for trap model 1:1, at 6, 8, 10 and 13 m/s.

Fig. 7. Calculated efficiencies versus velocity for three traps.
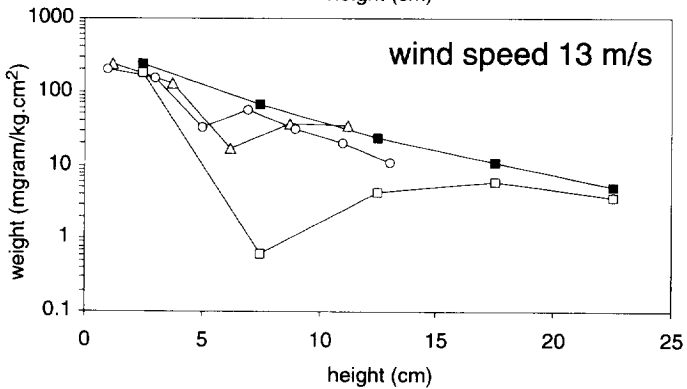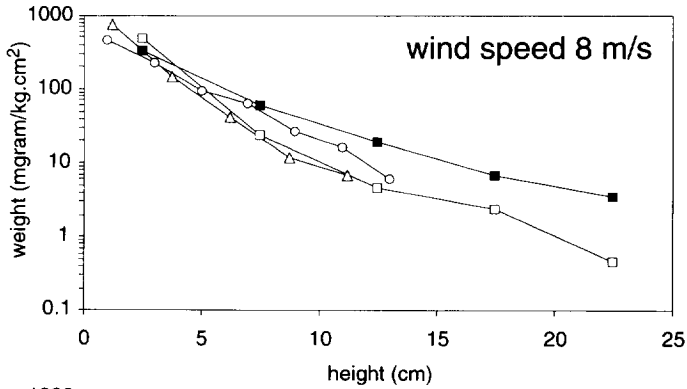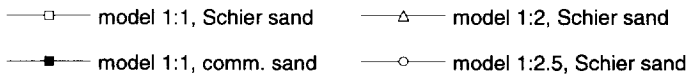

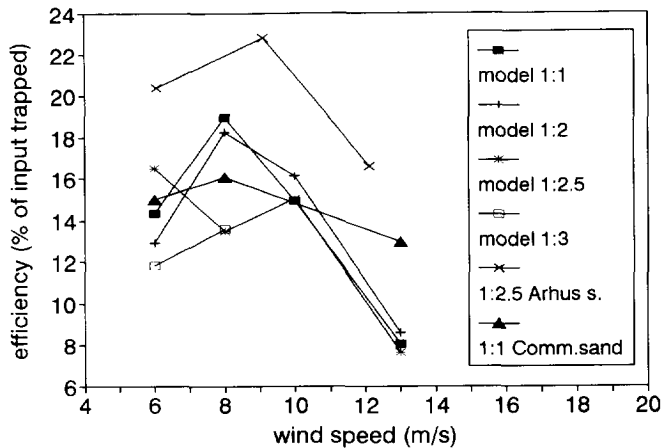Fig. 8. Averaged sediment curves for trap models 1:1, 1:2 and 1:2.5 at 8, and 13 m/s.

Fig. 9. Averaged efficiencies for several trap models, wind speeds and sands.

Catching efficiency is negatively influenced by several factors. During high wind velocities the amount of rebounding and saltating grains which pass the trap without being caught is higher than at low wind speeds. Catching efficiency of creep is poor due to obstruction by the lowest tray. If the lowest tray is not level with the surface, creeping grains will hit it and move around the trap. As changes in the level of the surface are frequently observed during transport of sand, this is a serious problem.

In the wind tunnel experiments the lowest tray was placed with the edges on top of the tunnel floor. For the 1:1 model the thickness of this edge amounts to 2 mm. As a result, grains which are transported between the surface and a height of 2 mm ("creep") will be deflected by the tray. This effect will be reduced for higher wind speeds, when the amount of grains moving close to the surface diminishes (as is reflected in the sediment curves of Fig. 6).

As a result the highest efficiencies are observed for wind speeds of 8 m/s. The efficiency is about 18% for sand with a mean grain-size of 180 μm and 20% for a slightly coarser and less well-sorted sand with mean grain-size of 205 μm. For lower wind speeds, efficiency decreases because of the increasing importance of creep. For higher wind speeds, efficiency is reduced because of an increasing loss by blowout.

4.3. Comparison with isokinetic trap

Table 2 shows the results of the experiments performed in the Århus wind tunnel. Since the sand used in the Århus experiments is coarser (mean 240 μm), derived efficiencies are higher. In these experiments efficiency increases initially with increasing wind speed and then decreases (Fig. 9). To compare the results, wind speeds at a height of 0.40 m are calculated assuming a logarithmic wind profile and a roughness length of 0.2 mm.

5. Conclusions of efficiency experiments

From wind tunnel experiments it can be concluded that trap efficiency depends on wind speed, the occurrence of creep and grain-size distribution (mainly in terms of the mean and

Table 2
Results of experiments performed in the Århus wind tunnel

Friction velocity (m/s)	Amount of sand trapped (kg/m.s $* 10^{-4}$)		η_s^a
	Isokinetic trap	Trap model 1:2.5	
0.4	77.2	15.7	20.4
0.6	271.3	61.6	22.8
0.8	642.8	106.8	16.3

[a] η_s calculated with effective width $= 0.04$ m.

sorting). Catching efficiency is highest at wind speeds of about 8 m/s. (This speed, at 0.40 m above the tunnel floor, corresponds to about 11 m/s at 2 m height in the field.) At higher wind speeds loss by blowout of already caught sand causes a significant decrease in efficiency. At lower wind speeds a relatively large part of the sand encounters the edge of the lowest tray and moves around the trap without being caught. Averaged efficiencies for all tests are presented in Fig. 9.

Field experiments indicate that on moist sand efficiency increases with about 10%, caused by an increasing stickiness of grains.

6. Discussion

Despite the relatively low efficiencies, we believe that our traps have some important advantages. Installation in the field is very easy, therefore measurements can be performed simultaneously on the beach and on several locations in the foredunes. This has proved to be very useful for studying changes in sediment fluxes between beach and foredunes. The height of the traps can be adjusted to suit the transport mechanism. The division into vertical compartments makes it possible to examine sediment samples from several heights.

The main disadvantages of the traps are the large disturbance that they make to the flow resulting in a low efficiency and problems with trapping of creeping grains. In particular the positioning of the trap level to the surface is very difficult, and impossible in cases where changes in surface height occur during sediment transport.

6.1. Estimation of trapped amounts when storage capacity is exceeded

Occasionally the sediment transport rate at the beach was very high. When exposure time of the traps was too long, the storage capacity of the lowest tray could be exceeded (usually when the content was larger than 250 gram). In order to make a calculation of the transport rates, the amount of sand which passed the trap must be estimated. Using the linear relationship between log(weight) and height, the amount in the lowest tray can be predicted by fitting a linear regression line through the log(weights) of the upper trays. Entering the effective height of the lowest tray in the regression equation gives an estimation of the expected content.
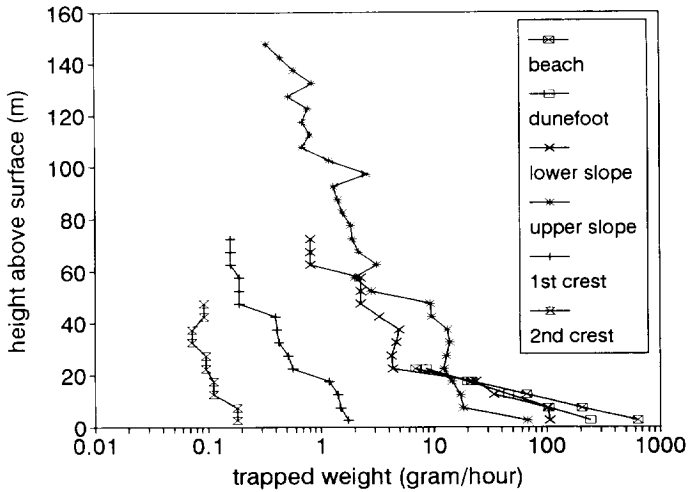
Fig. 10. Sediment curves measured on Schiermonnikoog, 16 April 1991.

6.2. Sediment flux measurements

Differences in transport mechanisms between the beach and dune environment are clearly visible from the sediment curves (Fig. 10). On the beach the decrease in sand content with height is very sharp, while on the foredunes the sand reaches much higher altitudes. A (dynamic) sediment budget can be derived by calculating the fluxes of sand that pass several points in the system. An example is given in Fig. 11. The flux on the beach is constant, but declines very rapidly landward from the dunefoot, which means that the sand is deposited. The zone with the sharpest decrease in flux corresponds with the zone of maximum deposition during the field measurements. The amount of sand which passes the foredune is negligible. The large gradient in sand input has important ecological consequences which are reflected in the vegetation.
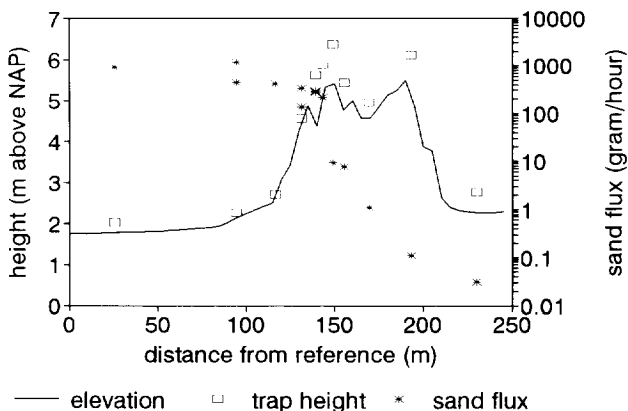

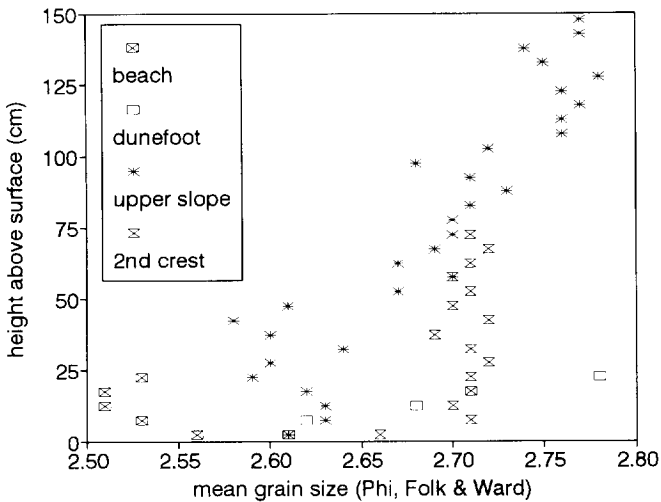Fig. 11. Sediment flux over foredune measured on Schiermonnikoog, 16 April 1991.

Fig. 12. Mean grain-size (according to Folk and Ward, 1957) versus height of samples trapped 16 April 1991.

6.3. Grain-size analysis of sand "in transport"

Information on the sediment in transport and the changes in grain-size population during transport can be derived from analysis of trapped sediment. Samples from one trap (vertical profile) provide insight into the composition of the saltation cloud. On the beach the mean grain-size of the samples seems to increase with height (Fig. 12). For all other profiles near the dunefoot and on the slope, grain-size decreases with height. On the crest locally no relationship between height and grain-size is visible, probably due to high turbulence. From beach to crest the mean grain-size of the sediment in transport decreases by approximately 0.2ϕ. Changes in grain-size during transport are discussed in detail by Arens (1994).

6.4. Improvements

Catching efficiency would increase considerably if the effect of blowout was diminished, and if trapping of creep could be improved. Reducing loss by blowout might be achieved by modifying the height of the trays. Another solution would be to fill the trays with large elements, for example marbles. The empty spaces between the marbles could trap grains which would then be protected from blowout (Yaalon, pers. commun., 1993). The decrease in storage capacity caused by the use of marbles could be offset by increasing the size of the trap, especially the size of the lowest tray. Another solution is to fill the trays with water which, however, makes emptying of the traps very time consuming.

The shape of the lowest tray must be adapted in order to improve the catching capacity for creep. In particular the contact with the surrounding surface should be improved, perhaps by making the edges of the lowest tray very wide (about 0.20 m) instead of using a square plate at the bottom of the trap.

Acknowledgements

References

Al-Khalaf, A., 1986. Specification and calibration of Bagnold's model for sand transport: Urayq al Buldan Dunefield, Central Saudi Arabia. Indiana University, unpublished PhD diss.

Arens, S.M., 1992. Transport of sand into the foredunes of Schiermonnikoog; report on the field measurements 1990–1991. Report, University of Amsterdam (in Dutch), 61 pp.

Arens, S.M., 1994. Aeolian processes in the Dutch foredunes. PhD thesis, University of Amsterdam, The Netherlands, 150 pp.

Arens, S.M., van Kaam-Peters, H.M.E. and van Boxel, J.H., in press. Air flow over foredunes and implications for sand transport. Earth Surface Processes and Landforms.

Bagnold, R.A., 1954. The Physics of Blown Sand and Desert Dunes, 2nd edition. Methuen, London, 265 pp.

De Ploey, J., 1980. Some field measurements and experimental data on wind-blown sand. In: M. de Boodt and D. Gabriels (Editors), Assessment of Erosion. Wiley, pp. 541–552.

Folk, R.L. and Ward, W.C., 1957. Brazos River Bar: a study on the significance of grain-size parameters. J. Sed. Petrol., 27: 3–26.

Fryberger, S.G., Al-Sari, A.M., Clisham, Th.J., Rizvi, S.A.R. and Al-Hinai, K.G., 1984. Wind sedimentation in the Jafurah sand sea, Saudi Arabia. Sedimentology, 31: 413–431.

Horikawa, K. and Shen, W., 1960. Sand movement by wind action (on the characteristics of sand traps). US Army Corps of Engineers, Beach Erosion Board, Tech. Memo. 119, USA, 51 pp.

Jensen, J.L., Rasmussen, K.R., Sørensen, M. and Willetts, B.B., 1984. The Hanstholm experiment 1982. Sand grain saltation on a beach. Dept. Theoretical Statistics, Institute of Mathematics, Univ. Århus, Denmark, Research Report 125.

Knottnerus, D.J.C., 1979. Wind erosion research by means of a wind tunnel. Measures to control wind erosion of soil and other materials for reasons of economy and health. Report, Institute for Soil Fertility, Haren, The Netherlands, 14 pp.

Leatherman, S.P., 1978. A new eolian sand trap design. Sedimentology, 25: 303–306.

Pye, K. and Tsoar, H., 1990. Aeolian Sand and Sand Dunes. Unwin Hyman Ltd, London, 396 pp.

Rasmussen, K.R. and Mikkelsen, H.E., 1988. Aeolian transport in a boundary layer wind tunnel. Geoskrifter, 29, Århus University, Denmark, 35 pp.

Rosen, P.S., 1978. An efficient, low cost, aeolian sampling system. Sci. Tech. Notes, Current Res. Part A, Geol. Surv. Can., Pap. 78–1A: 531–532.